NOAA Technical Memorandum NESS 64

CENTRAL PROCESSING AND ANALYSIS OF GEOSTATIONARY SATELLITE DATA

Washington, D.C.
March 1975

National Environmental Satellite Service Series

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C. L. Bristor, Editor

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NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
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CONTENTS

Editor's Preface iii
Acknowledgments iv
Acronyms v
Abstract 1
1. An Overview of the GOES Data Flow and Processing Facilities . . 2
2. SMS/GOES Spacecraft Tracking, Orbital Determination, and Prediction 21
3. Attitude Determination Support for the SMS/GOES Satellites . . . 26
4. Data Processing Support for Spacecraft Operations 33
5. Earth Locator Grids for VISSR Images 37
6. Operational Mapping of VISSR Imagery 44
7. Diagnostic Tools for Quality Assessment of VISSR Data 48
8. VISSR Data Calibration 59
9. VISSR Display Products from the Central Computer Operations . . 66
10. VISSR Picture Animation and Movie Loops 76
11. The Man-Machine Interactive Processing System 83
12. The Automatic Extraction of Wind Estimates from VISSR Data . . . 94
13. The GOES Wind Operation 111
14. Manual Analysis of VISSR Data 122
15. Sea Surface Temperature from VISSR Data 128
16. GOES Product Archiving Activities 133
17. Quality Assurance and Product Monitoring 139
18. Further Outlook for GOES 146
References 151

EDITOR'S PREFACE

With the launch of NASA's first Applications Technology Satellite (ATS-1) in late 1966, prolonged views of the earth-atmosphere scene first became a reality. Widespread experimentation with the spin scan image data from both ATS-1 and ATS-3 soon evolved into operational procedures, and by June, 1969, cloud motions measured from picture sequences were being routinely produced as wind observation estimates.

In May 1974, NASA launched its first Synchronous Meteorological Satellite (SMS-1) as the first spacecraft in NOAA's newly approved Geostationary Operational Environmental Satellite (GOES) program. With continuous day and night imaging of much of the Western Hemisphere, strong impetus now exists for an expanded product line based on data from the two-spacecraft GOES operation. The National Environmental Satellite Service has recently established a field service organization which is now helping to apply the new image data to the forecast and warning missions of the National Weather Service. Applications groups and researchers are also exploring new techniques for increased exploitation of the dual channel image data to meet meteorological, oceanographic, and hydrologic needs.

Efforts toward the extraction of quantitative observations by computer are also moving ahead. Our purpose is to describe these data processing and analysis activities in terms of the day-to-day operational production schedule. Once the digital data bit streams arrive at the processing facility, they progress through a sequence of processing steps. With an operational staff of some 150 technicians, programmers, and analysts, and a diversity of computers and image data handling devices, the raw material is transformed into a substantial list of products which are made available to many users on a near-real-time, continuous basis.

In this report we trace the flow of raw data into the central processing system and describe the steps taken along the way as usable observational outputs are produced. Many specialities are reflected in the various processing stages, so the report is a collection of separate descriptions by those most knowledgeable in these several areas. With the papers organized in a step-wise fashion, the reader will hopefully obtain a clear overview of the entire transformation process.

Since many of the descriptions involve items with long technical names, acronyms have been employed extensively. Although each acronym is identified at the point of first usage, an acronym glossary has been provided for those who may wish to read only isolated sections of the report.

ACKNOWLEDGMENTS

Apart from named authors of each of the papers herein, many others have contributed to this memorandum. Most draft material was typed by Bobbie Michael, and James Ainsworth provided valuable editorial assistance. Special thanks are due Paul E. Lehr, NESS and NOS Editorial Coordinator, and his staff for final editing and preparations for printing.

ACRONYMS

ADAC	Automatic Data Acquisition Controller
ATS	Applications Technology Satellite
CDA	Command and Data Acquisition (Station)
CPU	Central Processing Unit
CRT	Cathode Ray Tube
DAPAF	Data Acquisition Processing and Analysis Facility
DMD/FET	Digital Muirhead Display/Facsimile Encoder Transmitter
DOSS	Day One SMS System
DUS	Data Utilization Stations
EDS	Environmental Data Service
EPS	Energetic Particle Sensor
FFT	Fast Fourier Transformation
FOFAX	Forecast Office Facsimile Network
GARP	Global Atmospheric Research Program
GATE	GARP Atlantic Tropical Experiment
GOES	Geostationary Operational Environmental Satellite
IR	Infrared Channel
ITOS	Improved TIROS Operational Satellite
MTF	Modulation Transfer Function
NAFAX	National Facsimile Network
MMIPS	Man-Machine Interactive Processing System
NASA	National Aeronautics and Space Administration
NCC	National Climatic Center
NESS	National Environmental Satellite Service
NGSDC	National Geophysical and Solar-Terrestrial Data Center
NMC	National Meteorological Center
NOAA	National Oceanic and Atmospheric Administration
PICATT	Horizon Picture Attitude Program
PRWG	Product Review Working Group
SBRC	Santa Barbara Research Center
S/DB	Synchronizer/Data Buffer
SDSB	Satellite Data Services Branch
SEL	Space Environment Laboratory (NOAA)
SEMS	Space Environment Monitor Subsystem
SFSD	Satellite Field Service Division
SFSS	Satellite Field Service Station
SMS	Synchronous Meteorological Satellite
SOCC	Satellite Operations Control Center
SR	Scanning Radiometer
SRIR	Scanning Radiometer, Infrared Sensor
SST	Sea Surface Temperature
STADAN	Space Tracking and Data Acquisition Network
TARS	Turn Around Ranging Station
TRRR	Trilateration Range and Range Rate (System)
UHF	Ultra High Frequency

VHRR	Very High Resolution Radiometer
VIS	Visible Channel
VISSR	Visible Infrared Spin Scan Radiometer
VTPR	Vertical Temperature Profile Radiometer
WEFAX	Weather Facsimile Network
WMO	World Meteorological Organization
WWB	World Weather Building

CENTRAL PROCESSING AND ANALYSIS OF GEOSTATIONARY SATELLITE DATA

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ABSTRACT. This report provides an in-depth description of the central processing and analysis activities of the National Environmental Satellite Service as related to the newly established Geostationary Operational Environmental Satellite (GOES) program. Treatment of the incoming data stream during the process of transformation is explained by means of a series of papers prepared by experts in the several segments of the processing and analysis activity. Navigation and spacecraft operations support are discussed together with the earth location of image data. Displays and manually derived products are discussed. The automatic extraction of quantitative information from image data is also stated. A mixed man-machine activity, by which calculating and data manipulating tasks are assigned to computers and judgmental decisions are made by human analysts, is described. A popular, yet substantive approach has been attempted. It is hoped that this approach will permit readers with a variety of technical backgrounds to obtain significant insight on our central processing operations.

1.

AN OVERVIEW OF THE GOES DATA FLOW AND PROCESSING FACILITIES

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INTRODUCTION

The primary purpose of this paper is to describe the various signal exchanges between the SMS/GOES satellites, and the several ground facilities of the National Environmental Satellite Service: the Command and Data Acquisition (CDA) station at Wallops Island, Va., the Spacecraft Operations Control Center (SOCC) and the Data Processing and Acquisition Facility (DAPAF) at Suitland, Md. An overview of the central processing equipment configuration is also provided. With this introduction the reader should, hopefully, be able to visualize the tasks arising from the various incoming data streams as related to both SOCC support and to the transformation of raw environmental sensor data into operational products.

Although detailed descriptions of the spacecraft and its sensor and communications facilities are available elsewhere (Tipkin 1971), a a limited description here may reduce the need to consult reference material--especially for those interested mainly in the DAPAF activities.

THE VISSR AND THE IMAGE DATA FLOW

The Visible and Infrared Spin Scan Radiometer (VISSR) is described in detail by Abbott (1974). Radiation from the scene enters the 16-in telescope aperture, reflects off the object space-scan mirror, and passes through a Ritchey-Chretien optical system onto the detector arrays. Energy is gathered by 8 visible channel (VIS) sensors and 2 infrared (IR) sensors. In the visible, energy is collected by 8 fiber optics apertures and passe d onto separate photomultiplier tubes (PMTs) which respond in the 0.55- to 0.75-μm range. In the infrared, scene radiation is also relayed and filtered by the optical system to the two Hg-Cd-Te detectors mounted on a plate that is cooled by a radiation device to a controlled temperature of 95°K. The optical filter passes only radiation in the 10.5- to 12.6-μm wavelength region. The optical system can be focused by command.

The SMS/GOES spacecraft orbit at geostationary altitude (approximately 36,000 km); each spins about an axis oriented nearly parallel to the

Earth's spin axis. Just before the 16-in mirror encounters the Earth, the spacecraft timing system allows data sampling to begin and sampling continues until the Earth scene is traversed. An 8-km strip is viewed during each Earth sweep. After each sweep, the mirror is stepped 192 microradians so that an adjacent (southward) strip is viewed on the next rotation. This stepping process repeats 1,821 times to acquire an entire Earth frame (picture) in both IR and VIS.

The sensors are arranged so that an Earth object is first detected by the VIS sensors then later by the IR sensors. IR sampling occurs every 8 μs; each VIS channel is sampled every 2 μs. Samples are passed from the analog-to-digital converters to the VDM (VISSR Digital Multiplexer) from which they emerge as a combined bit stream. The VDM includes bits in the data stream which specify the step position of the mirror. Sun pulse and synchronization data, which originate in the Attitude Determination and Control (ADAC) unit, are also added to the bit stream. The sync bits are added to mark the start of useful data. Separate formats exist for the 2-km and 1-km transmission modes. The following table specifies the more common 1-km format.

Bit stream format for 1-km mode for a single revolution of the spacecraft

01010101 - - - - 01 (preamble) | 16 bits (Sync) | 12 bits (mirror position) | 8 bits (Sun data) | 20 bits (filler) — Word 0

8 bits
$(IR_1)(VIS_1)(VIS_2)(VIS_3)(VIS_4)(VIS_5)$ - - - - (VIS_8) — Word 1

(Sync) (VIS_1) - - - - (VIS_8) — Word 2

(IR_2) (VIS_1) - - - - (VIS_8) — Word 3

(Sync) (VIS_1) - - - - (VIS_8) — Word 4

(IR_1) (VIS_1) - - - - (VIS_8) — Word 5

. . . etc. to Word 3822

Once the bit stream content is established, it is converted to a two-channel serial form for down-link quadriphase modulation. In the 1-km mode, the resulting input at the Wallops Island Command and Data Acquisition (CDA) station arrives at a 28 megabit per second rate. From the 20-m diameter S-band antenna system, the received signal is passed to the Four Phase Demodulator/Demultiplexer which locks on the carrier signal, then attains bit sync lock, and ascertains start of the sensor data. After the signal has again been transformed into machine-readable bits, it is transferred to the computerized Synchronizer-Data Buffer (S/DB).

The primary function of the S/DB is to provide a reordered and synchronous data source for retransmission to users by means of relay through the spacecraft. Only 5 percent of each spin cycle is utilized in direct image data acquisition, so over 550 ms of each spin period are available for a slower retransmission of data. The resulting retransmission contains line-by-line image samples at less than 2 megabits per second, with precise synchronization, so that less elaborate ground stations may receive the data for direct recording on a display device.

In the buffering process, the S/DB also performs certain preprocessing functions. Upon entering the S/DB, the IR and visible data are separated; the IR goes to a GTE TEMPO computer and the visible passes through special hardware processing units. The visible data are first adjusted (via lookup table) for each sensor's bias, gain, and other individual characteristics, and then are interpolated, sampled, and placed in an output buffer. (There are 3 selectable interpolations and 2 alternate sampling methods.) The IR data are interpolated and sampled in the same manner by the IR sync processor on the way to the computer. In the computer, the IR responses are adjusted for individual sensor characteristics, and converted to temperature through lookup tables. In the preferred sampling mode the resulting line sample array corresponds to a fixed angular domain despite the possibility of variations related to satellite spin rate fluctuation. Compensation is also included for spatial alinement of the sensors in the detector array.

The appending of auxiliary information is another function performed by the S/DB. Spacecraft parameters, operating status, and other housekeeping data are reformatted in the S/DB computer and appended to each IR scan as further documentation. An important part of this added information is Earth locator gridding information, precalculated at DAPAF, forwarded to the CDA by a computer-to-computer transfer system, and appended within the S/DB as a 9th bit linked to each IR sample. Output is routed to a modulator for retransmission to the spacecraft. Lower volume IR transmissions are also made through a microwave link direct to DAPAD. Timing for most of the S/DB functions is provided by the Central Timing Unit (CTU) using input from the spacecraft Sun pulse, the Sun-spacecraft-Earth relationship, and internal clocks.

The S/DB can be selected to change data resolutions before retransmission in the following manner:

Visible:	1 km (Mode A) (no change)
	2 km (Mode B)
	8 km (Mode C)
IR:	8 x 4 km (no change)
	8 x 8 km (Mode D and NESS land line).

In all, modes (A, B, C, or D) 8 x 4 IR data are part of the retransmission. The IR channels can also be averaged together or they can be individually selected.

The retransmitted IR_1 and IR_2 VISSR data are received at Suitland through an antenna 8 meters in diameter, demodulated by a PSK (Phase Shift Key) demodulator, and passed to the DIE (Digital Interface Electronics) where it is bit and frame synchronized, separated into IR and visual data, and transferred to the VIC (VISSR Ingest Computer). An antenna and antenna controls are shown in figures 1-1 and 1-2. The VIC is a system that receives the VISSR data, transfers all the IR, and selected portions or "sectors" of the visual data, at various resolutions, to magnetic tape. (See VIC view in figure 1-3.) The VIC can then read the data from tape, reformat it, and transmit it to a facsimile display device or to a Muirhead film recorder. The magnetic tape can be removed and taken to the IBM 360/195 for further processing. The resolutions available from 1-km visual data input are:

1 km (1/8th of the Earth disk),

2 km (1/2 of the Earth disk), and

4 km (all of the Earth disk).

From 2-km visual data, the resolutions are:

2 km (1/2 of the Earth disk),

4 km (all the Earth disk), and

8 km (all the Earth disk).

The full Earth disk IR is always present on the magnetic tape at 8- x 4-km resolution. Once the direct linkage to the IBM system is fully operational, incoming data may be relayed directly to large disk storage with less restriction. Depending upon disk allocation, full disk 1-km images may then be stored for further processing. VISSR data calibration is discussed in section 8 of this memorandum.

Apart from the primary VISSR data stream, the S-band system exchanges other information between the spacecraft and the CDA station. To facilitate the discussion, we have attempted to portray the entire system in three diagrams. Figure 1-4 indicates the basic signal exchanges and internal functions at the spacecraft. Figure 1-5 provides a similar treatment for the CDA station, and figure 1-6 treats activities within DAPAF and other portions of the Suitland-World Weather Building complex.

SPACECRAFT COMMANDS

Spacecraft commands originate at Suitland and are transmitted by voice quality line to the CDA station where they are input to the command encoder by switches. They are then routed through the command modulator via the S-band antenna to the spacecraft. Within the spacecraft the command system interprets and routes each command to the appropriate subsystems.

The command verification information subsequently monitored at Suitland is obtained from two sources. The first source, timewise, are the commands that arrive at Suitland as part of the Station Events data stream. These represent the commands transmitted through the command encoder at the CDA station and registered there as Station Events. The second source are the commands that arrive at Suitland as part of the PCM Telemetry data stream. These represent commands executed on the spacecraft and verified through signals received at the CDA station.

At Suitland the UNIVAC 6000/6135 computer receives command information from the CDA station in real time. (Figure 1-7 shows some of the specialized interface equipment.) The computer composites and formats information from both sources. By keyboard command, a CRT displays all commands sent to the spacecraft together with appropriate time tags and records of disposition. Figure 1-8 shows the Keyboard/CRT control stations in the Spacecraft Operations Control Center (SOCC).

HOUSEKEEPING TELEMETRY

Pulse Code Modulation (PCM) telemetry data are accumulated from a variety of spacecraft sources. Once collected, all information is routed through the spacecraft transmitter-antenna system to the CDA station. On the ground the telemetry receiver routes the signals to the PCM Data Handling Equipment (PCM/DHE). Here the information is stripped out in machine readable form and passed to the Real Time Data Unit (RTDU) where it is multiplexed and transmitted via 3-kHz land line to DAPAF.

At Suitland, a discriminator separates PCM telemetry data from other RTDU-generated information, and a front end signal conditioning module relays machine readable data to the UNIVAC processor. Here the raw values are transformed into proper physical units and presented in several output formats. At the option of the SOCC controller, outputs can be obtained on the computer printer, on CRT displays, and on magnetic tape for archiving and subsequent analysis.

The PCM telemetry data are displayed on the CRT in two ways. One display shows groups of selected PCM telemetry points and the other combines ground station events data to make up a CRT commands display.

The digital magnetic tapes are input to a retrieval program on the IBM 360/195 computer which outputs listings or plots of selected telemetry points. The hard copy outputs are used by SOCC for data and sensor evaluation.

GROUND STATION EVENTS

The ground station events originate at the CDA and are output by the Events Multiplexer and transmitted over a 3-kHz line to Suitland. The events are sent through a signal conditioning device and then input to the UNIVAC real-time computer. As in the case of telemetry, the data are processed and output is supplied to the SOCC CRT. The ground station events data are supplied to the CRT in two ways. There is one display for groups of selected events. In addition, the ground station events and the PCM telemetry data contribute to the Command display on the CRT.

ATTITUDE DATA FROM VISSR AND SUN-EARTH SENSORS

A separate set of sensors, mounted in a "fan" array, provide relatively coarse attitude information for use during maneuvers. Sun and Earth pulses from these sensors are formatted and inserted as part of the spacecraft telemetry data stream. At the CDA station, the received values are converted to time duration equivalents by an Attitude Data Unit within the RTDU.

The Sun-Earth data, multiplexed and forwarded to DAPAF as part of the telemetry bit stream, contain the following information:

Sensor identifier,

Sun pulse width (4-50 ms),

Earth pulse width (20-100 ms),

Time from leading edge of Sun pulse to leading edge of Earth pulse (0-1150 ms),

Spacecraft spin period (computed from leading edge of Sun to next leading edge of Sun, about 600 ms for 100-rpm spacecraft), and

Time tag (for each data set).

At Suitland, data sets are separated from other information in the incoming RTDU bit stream by a discriminator, and, as in other instances mentioned earlier, a signal conditioner provides the interface to the real-time UNIVAC preprocessor. The Sun-Earth data are accumulated on disk in 24-hour batches and are then formatted as input to the Sun-Earth attitude program. Options exist for alternate outputs on tape, line printer, or as a CRT display.

The VISSR horizon crossing image profiles provide an important alternate source of attitude information. With simple thresholding logic, the VISSR IR scans are utilized by the S/DB minicomputer to extract such horizon crossing measurements. These data form a part of the previously mentioned documentation data that accompany the 8-km IR imagery sent by microwave link to DAPAF. As in the case of Sun-Earth data, horizon inputs are saved on disk and formatted in 24-hr batches for use by a horizon attitude program.

Both Sun-Earth and horizon attitude programs are discussed in section 3 of this memorandum.

TRILATERATION RANGING DATA

The Trilateration Ranging Subsystem provides timed pulse slant range information for spacecraft position determination. A pulse initiated at the CDA station is returned by three routes: by direct "echo" return, by relay after receipt, and by retransmission at two Turn Around Relay Stations (TARS). "Frames" of time interval data are obtained through processing of the separate pulse tones, and the results are sent in real time from the dedicated CDA minicomputer to Suitland. Again, the data are accumulated on disk, then formatted as input for the orbit determination model as explained in section 2 of this memorandum.

IMAGE PRODUCT TRANSMISSIONS AND LOCAL DISPLAYS

A major portion of our large scale computer resource is used in generating a variety of image display products. (See section 9 of this memorandum.) Some of these are displayed locally and used as intermediate tools by analysts while others are disseminated on a scheduled basis to end users. A Digital Muirhead Display (DMD) device provides local photo products; facsimile transmissions are made on National Weather Service facsimile landline circuits and by satellite relay. A Weather Facsimile (WEFAX) experiment was carried out using NASA's Applications Technology Satellites (ATS-1 and 3); a similar operational S-band facility is now available on the SMS/GOES spacecraft. Figure 1-9 indicates the area served by the new dual spacecraft rebroadcast operation.

A minicomputer configuration within DAPAF provides the dedicated link between the large scale computers and the image product customer. Since it serves the dual functions of interfacing with the Digital Muirhead Display and providing a Facsimile Encoder-Transmitter, it is termed the DMD/FET. Three such units are interfaced with the large scale computers via direct linkage as well as by tape-to-tape linkage. Each has facility for driving local displays through digital-to-analog data transfer. Modulated carrier output is also available for transforming digital data records into analog image line signal trains for facsimile transmission. The facsimile output signal is relayed via 3-kHz landline from DAPAF to the CDA station, from which it is relayed without buffering directly to the satellite for rebroadcast.

THE DATA COLLECTION SYSTEM

The SMS/GOES spacecraft provide the means for communicating with low powered ground-based transmitters. A system is under development by which a variety of remotely-placed platforms with such facilities may relay local environmental measurements through the spacecraft to a central collection point. This Data Collection System (DCS) involves surface-based systems which are activated by local timer and others which are turned on by command through the spacecraft. Interrogation commands and associated platforms address identifiers are transmitted to the spacecraft via CDA S-band facilities. On the spacecraft these commands are separated from other commands and routed to a UHF transmitter which sends required signals to the remote platforms.

The present ground systems consist of a coupled pair of dedicated minicomputer systems by which commands pass from Suitland to the CDA station and through which platform data are returned. Only limited tests have been made to date, but results with test platforms have been successful. Each spacecraft is designed to accommodate approximately 10,000 remote platforms. Hundreds of platforms are being constructed, and we anticipate a full network operation within a few years.

LARGE SCALE COMPUTER SUPPORT

The central NOAA computer facility provides large scale support for satellite data processing operations. Located at Suitland, the current configuration consists of two IBM 360/195 mainframes with a large set of commonly accessible peripheral devices. Each Central Processor Unit (CPU) has two million bytes of main memory. The channel connections to disk storage, tape transports, high speed drums, and unit record equipment are shown in figure 1-10. The 32-spindle disk configuration (100 million bytes each) is configured on a completely shared basis which permits cross-communication between programs executing on the dual system.

The NESS operations area is directly connected to the NOAA system via a data channel to permit full speed tape and unit record operations to be performed at a location remote (by some 400 feet) from the NOAA system. Standard IBM software is used for system operations. Included are OS/MVT 21.7 and ASP 3.2.

The NESS operational interface currently is manual, i.e., data are buffered from the NESS ingest computer to magnetic tape. These tapes are then manually transferred to tape transports connected to the 360/195 system via the NESS (longline) channel for processing on the central computer system. A more direct connection is now underway. This more efficient mode of operation should reduce the chance for human error and will alleviate the problems of maintaining magnetic tape hardware compatibility. When fully operational, nine dedicated computers within DAPAF will be interconnected with the central facility.

The NESS uses more than 50% of the total computing resource and 30% of the online storage capacity for routine processing of satellite data. The average operational program performs at a 5-to-1 clock-to-CPU rate and requires 35% of the user memory space. These utilization figures are low because of the high volume of satellite data passed through the executing programs compared to the amount of CPU processing required for the problem execution.

Before substantial amounts of 1-km VISSR data can be processed, effective throughput must be improved; several efforts to make improvements are now underway. More effective block-time scheduling of input/output data reduces contention and improves transfer efficiency. Reductions in memory requirements are permitting more graceful multiprogramming of non-contending jobs. On the hardware side, additional storage and channel pathway facilities are needed. An additional controller was recently installed to provide separate data transfer channels for each set of eight disks. Double density disks and other augmentations are under consideration.

Figure 1-1.--One of two 8-meter parabolic antennae in primary Data Utilization Station (DUS) at Suitland, Md.

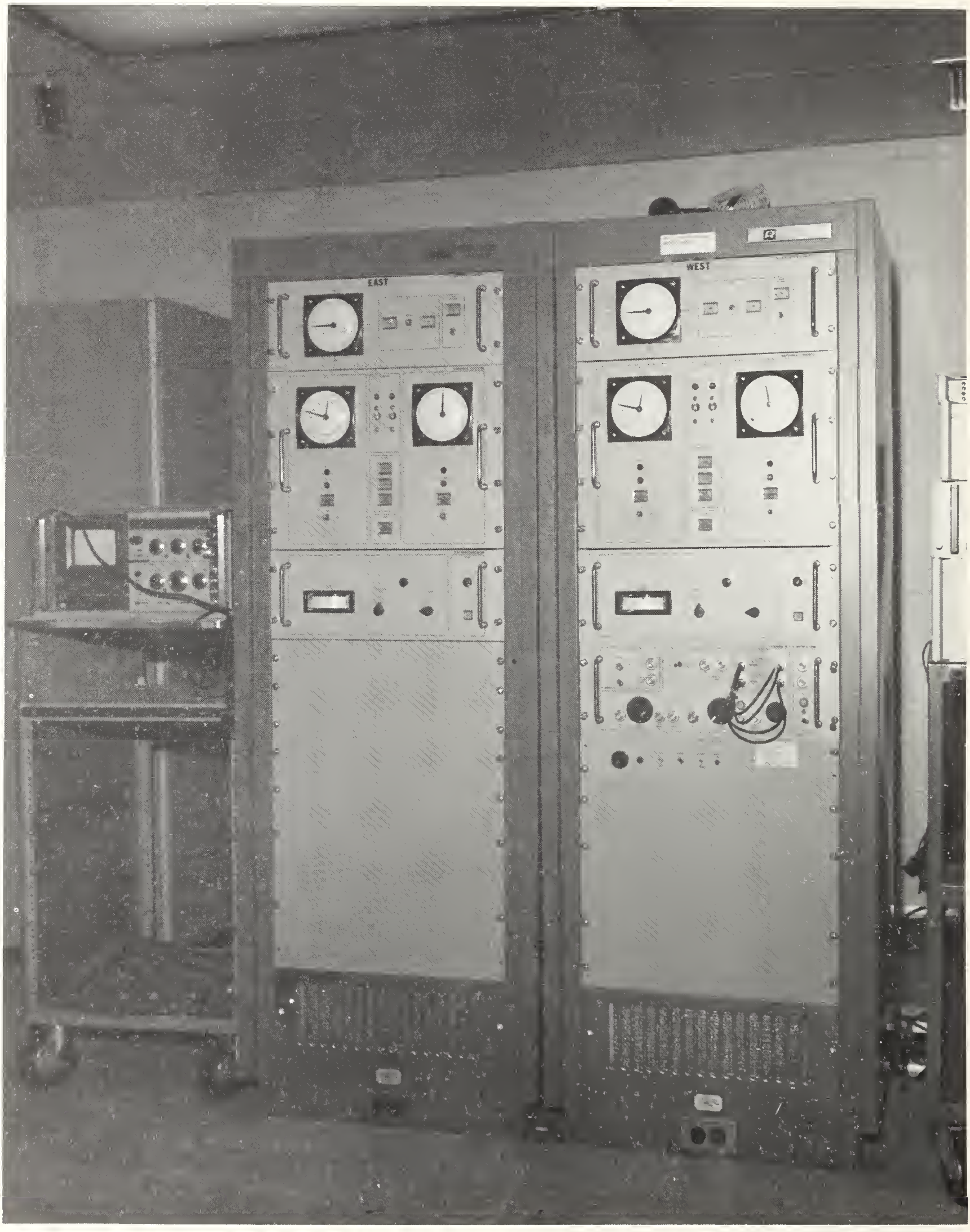

Figure 1-2.--Control panels for DUS antennae showing azimuth and elevation indicators and signal strength monitor (lower portion)

Figure 1-3.--VISSR ingest systems showing tape transports (above), teletype operator interface, GTE minicomputer (at operator eye level), and alphameric display CRT (behind operator and on unit at left)

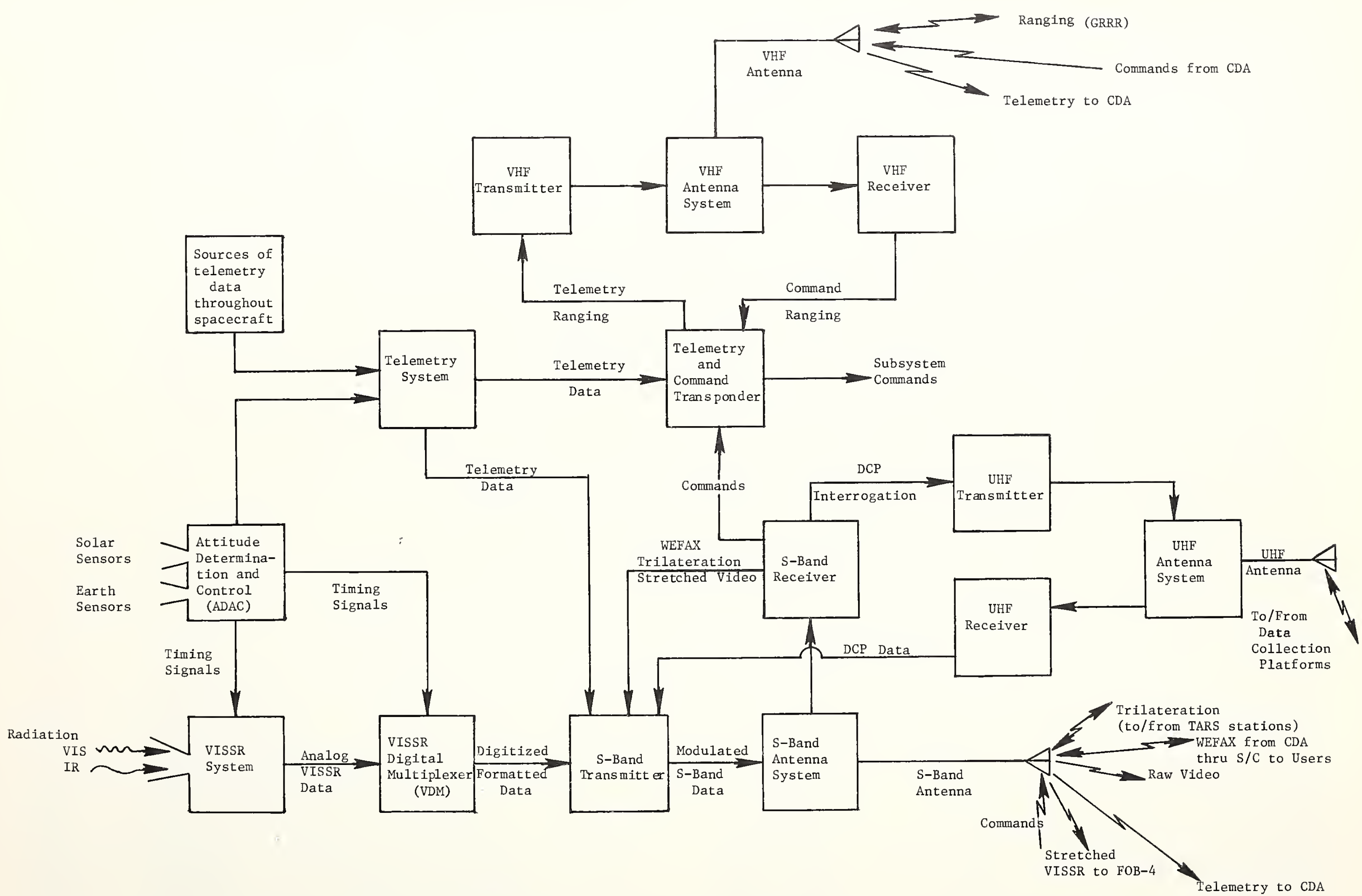

Figure 1-4.--Functional block diagram of SMS/GOES spacecraft electrical system as related to VISSR data and their application

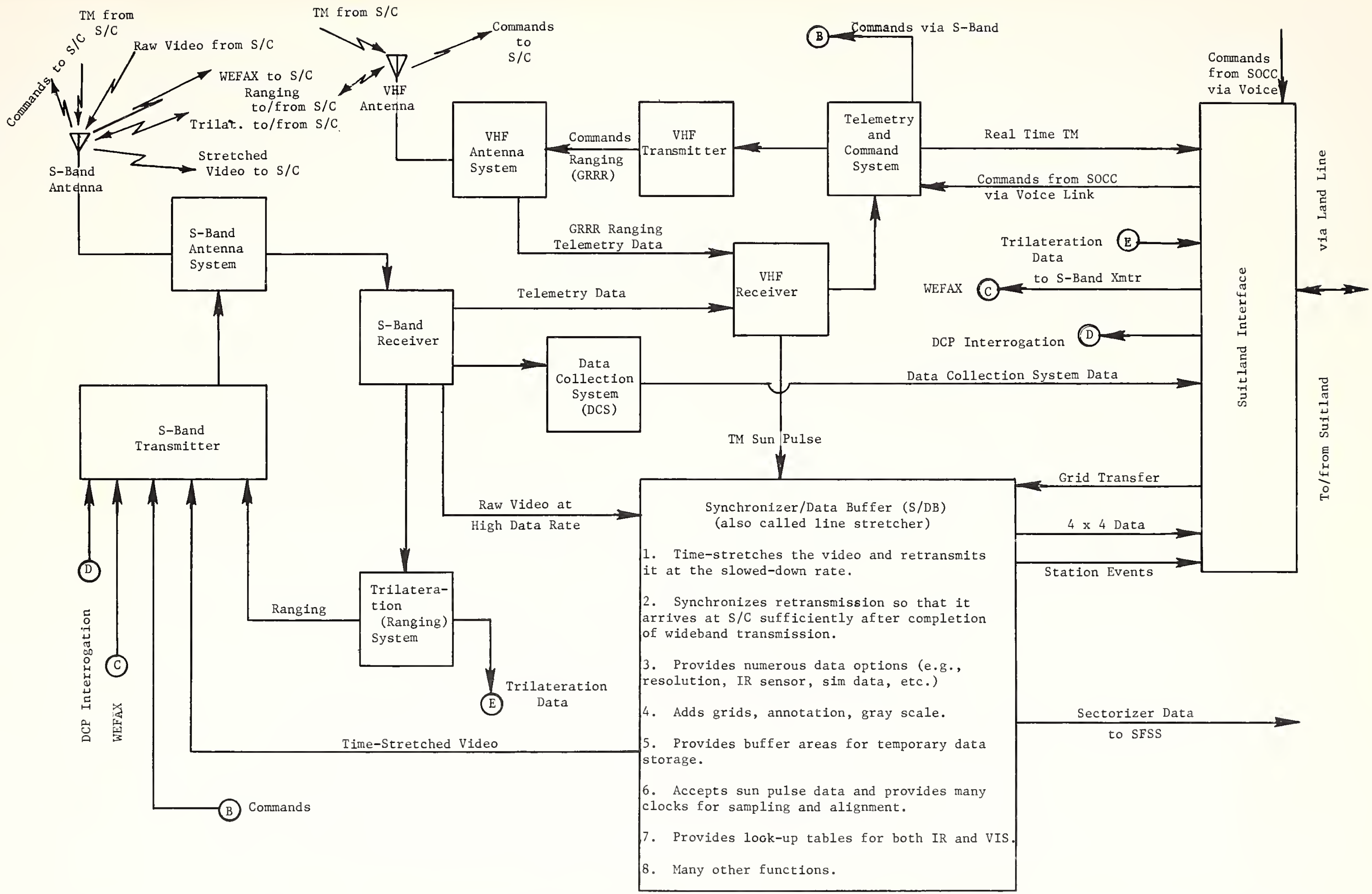

Figure 1-5.--Functional block diagram of the entire portion of the Wallops CDA related to the SMS/GOES system. The S/DB is the heart of the system.

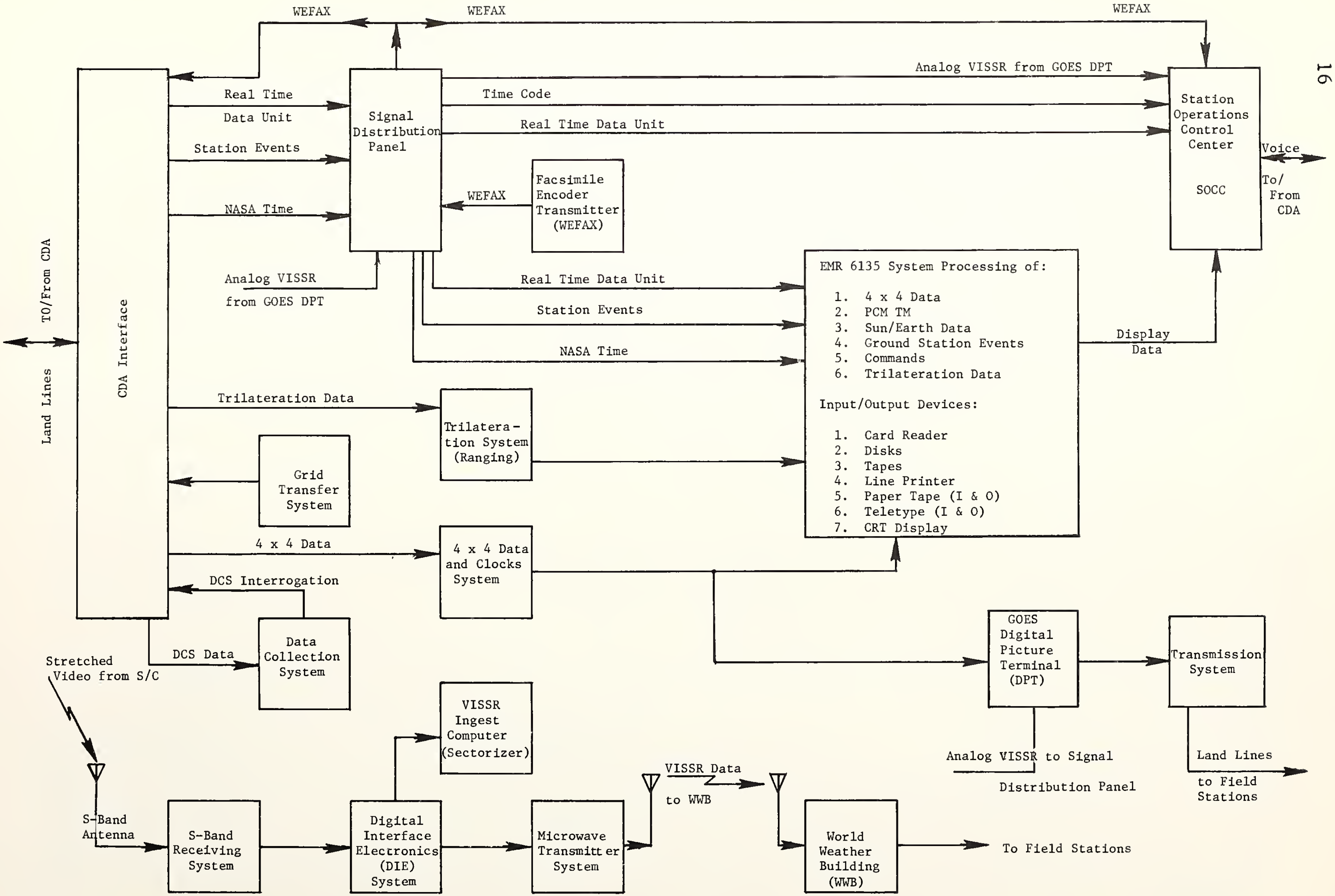

Figure 1-6.--General data flow of Suitland, Md., portion of SMS/GOES system. Most types of SMS/GOES data are handled here; much is stored.

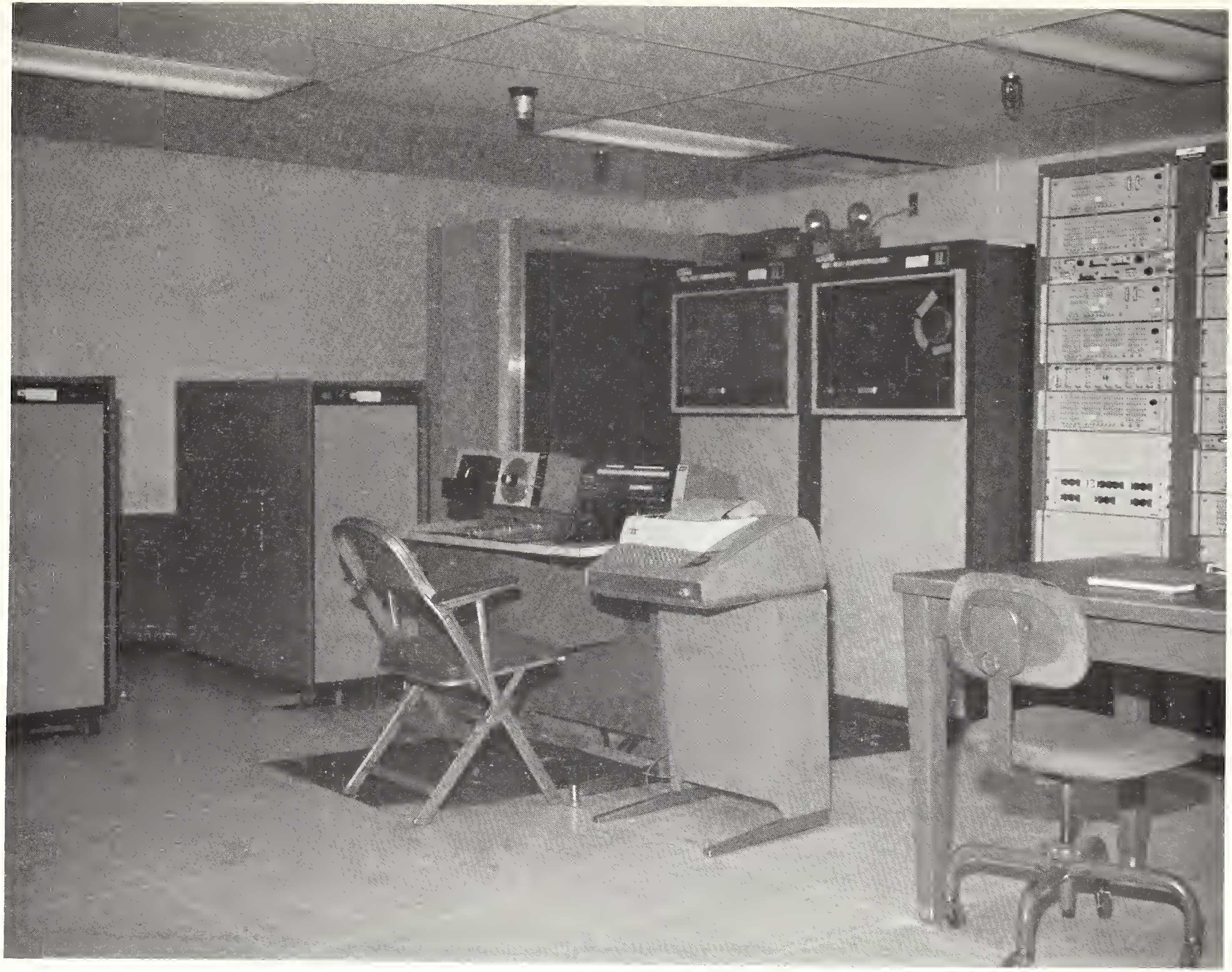

Figure 1-7.--UNIVAC 6000/6135 real-time computer system showing operator console, special incoming signal interface (right), and peripheral tape and disk equipment

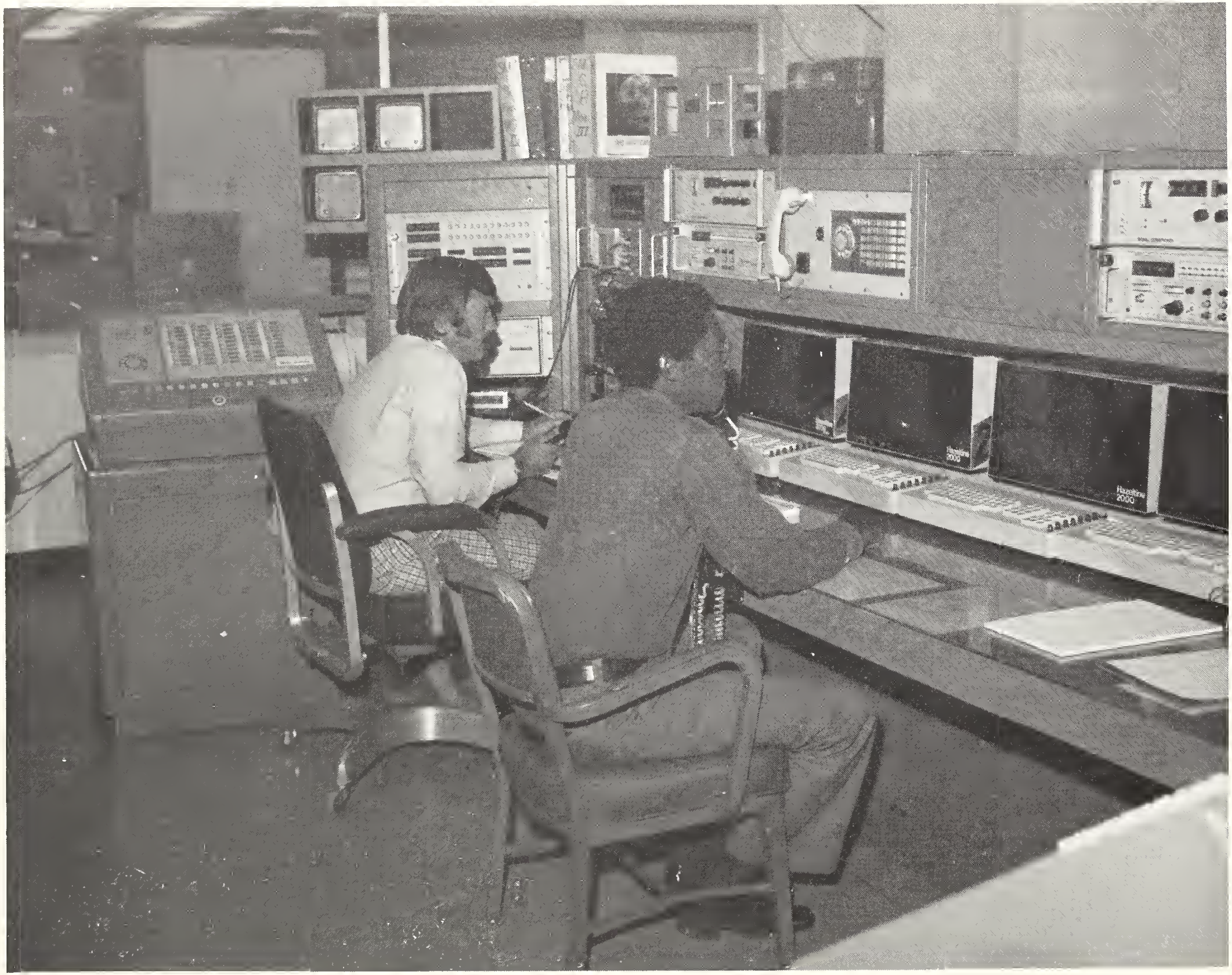

Figure 1-8.--SMS/GOES signal monitoring, communications, command and control facilities within the Spacecraft Operations and Control Center (SOCC) at Suitland. Four CRT keyboard terminals interface with the UNIVAC real-time processor system.

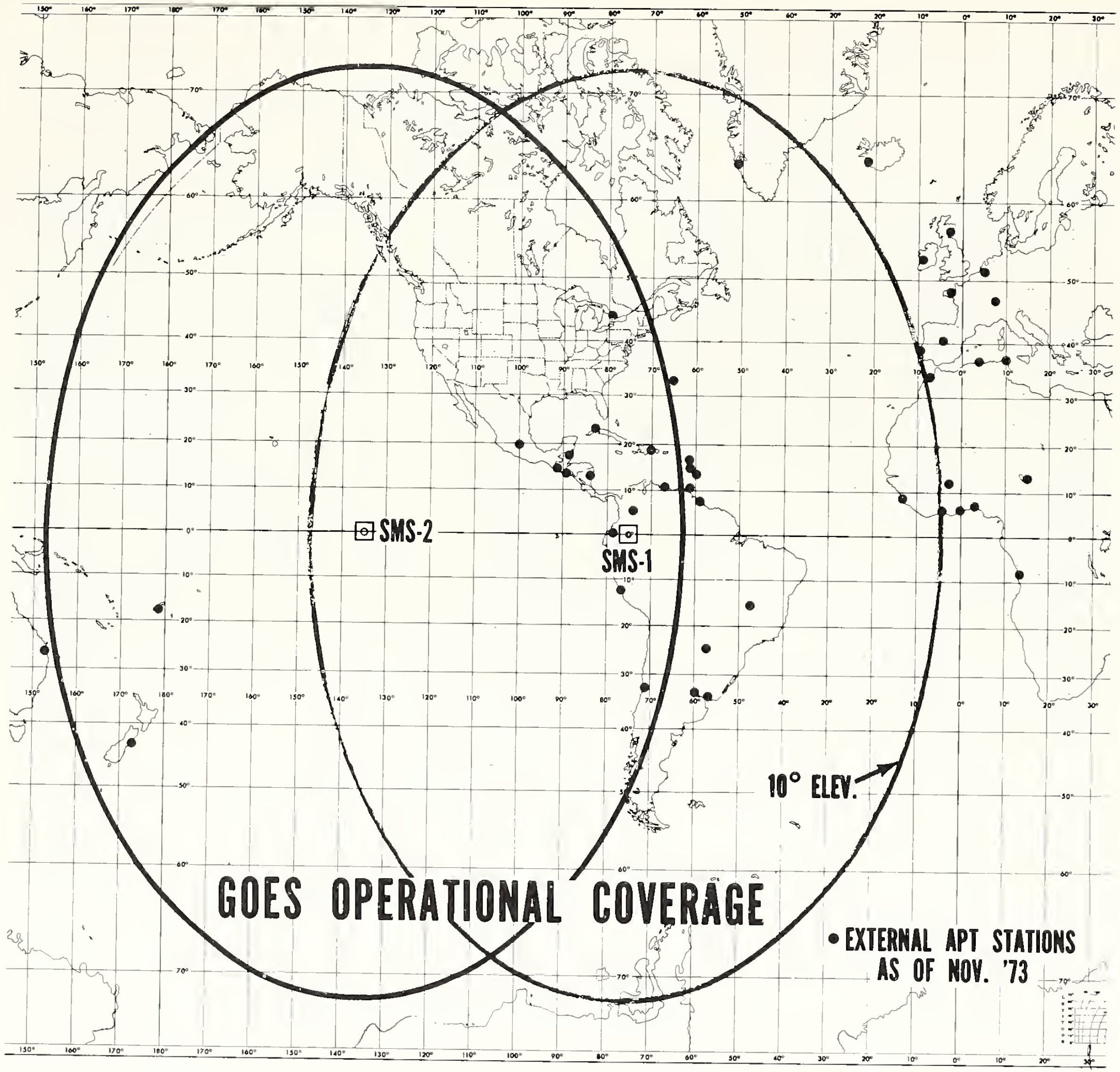

Figure 1-9.--The 10° elevation angle elipses indicate approximate area for which WEFAX coverage is provided by the dual satellite system. Known Automatic Picture Transmission (APT) receiving stations outside the United States (indicated by dots) are potential customers for this new S-band service.

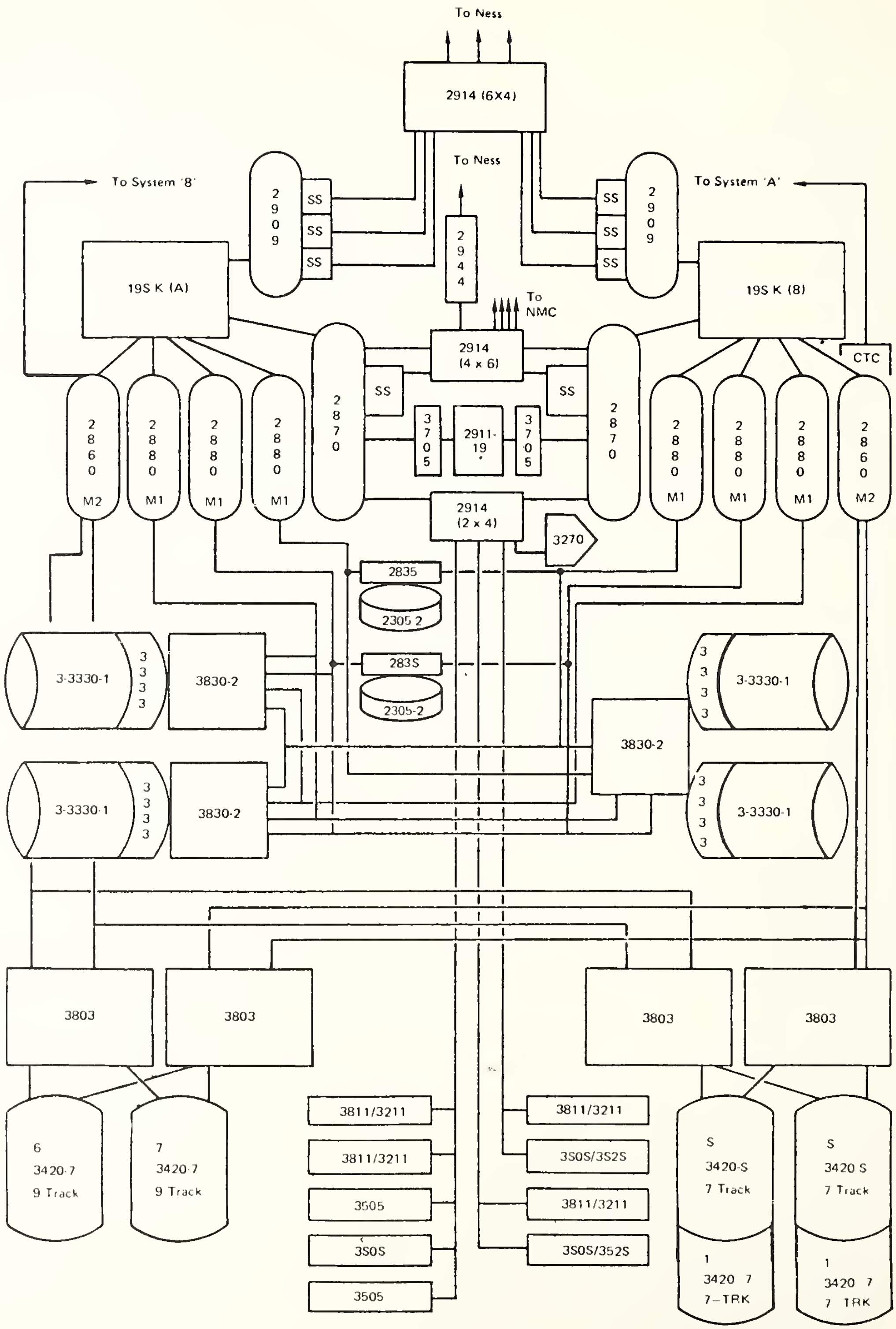

Figure 1-10.--Diagram of NOAA Central Computer Facility with dual IBM 360/195 system. Common disk access permits ready information exchange between multiprogrammed jobs running on either central processor.

2

SMS/GOES SPACECRAFT TRACKING, ORBITAL DETERMINATION AND PREDICTION

J. R. DeMeo

INTRODUCTION

For all previous NESS operations (including experimental operations with ATS), satellite position determination support has been provided by the NASA Space Tracking and Data Acquisition Network (STADAN). With the new GOES operation, NESS is now accepting prime responsibility and STADAN support is being projected only as emergency backup. This paper describes the new S-band trilateration system for obtaining the necessary ranging measurements and the 360 computer program packages for feeding this observational information into the orbital model for satellite position determination and prediction. The primary emphasis here is on the data processing operation, so this subject is the central topic of discussion.

THE TRILATERATION FACILITY

For SMS-1 the Trilateration Range and Range Rate (TRRR) system consists of three ranging stations (fig. 2-1):

1. Master range station located at Wallops Island, Va., as part of the CDA facility,

2. Turn-around ranging station, TARS-1, located at Ascension Island, and

3. Turn-around ranging station, TARS-2, located at Santiago, Chile.

Range measurements are initiated by a ranging unit at the CDA. The ranging unit generates tones that are transmitted to the TARS through the spacecraft. Each TARS transponds the signal it receives to a different radio frequency. Three receivers are used in the CDA to detect the returned ranging tones. Each range value is determined by comparing the phase difference of the transponded signal with a reference. The range rates on each of the three ranging links are computed by differencing adjacent (neighbor) range measurements and dividing by the difference in the time tags. The discrete tone system provides 3-m accuracy in the two-way range measurements.[1]

The TARS and unmanned system components are automatically triggered by the ranging commands from the CDA station so, except for periodic maintenance, no on-site operating personnel are required. The TRRR system is designed for

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[1] "Trilateration Range and Range Rate System," Vol. 1, CDA System Manual - Preliminary Draft, SCG 20671R, Nov. 1972.

fixed satellite position operation, and any movement to a new operating longitude requires reorientation of TARS antennas. Each TARS is a compact structure designed to require minimum maintenance (fig. 2-2).

Ranging data cannot be obtained during VISSR imaging cycles. Since there are 10-min free periods in the half hourly image acquisition schedule, ranging data are collected four to six times every 24 hours.

The following information is transmitted to DAPAF in Suitland, Md., from the TRRR system at the CDA for use in the orbit determination program:

1. Range (time delay)

   a. One way time delay, CDA to SMS

   b. One way time delay, CDA to SMS to TARS 1

   c. One way time delay, CDA to SMS to TARS 2

2. Range rate for the 3 ranging links

3. Data source identification (i.e., CDA, TARS-1, TARS-2)

4. Measurement time tags.

ORBITAL CALCULATIONS

The raw ranging data are received at Suitland on an EMR 6135 computer. The 6135 ingest program extracts the raw range data and writes it on magnetic tape for processing by the Trilateration Version 2 (TV-2) orbit determination program.

The TV-2 program, developed by the Hughes Aircraft Company, utilizes the simultaneous slant range data from 3 stations to determine the satellite state (position) $\{x_o, y_o, z_o, \dot{x}_o, \dot{y}_o, \dot{z}_o\}$ at an adopted epoch time, τ_o. A preprocessor in the program subtracts the one-way CDA range from the TARS measurements to produce slant range from the TARS stations to the spacecraft. TV-2 then solves three simultaneous triangles to obtain $x(\tau_o)$, $y(\tau_o)$, $z(\tau_o)$. An alternate mode for processing range rate data utilizes a truncated Taylor Series of the form

$$\rho(\tau) = x_1 + x_2\tau + x_3\tau^2 \qquad (1)$$

which provides a least-squares curve fit to small arcs (± 10 min) of range data. The range values (ρ) are then converted to range rate by differentiating equation (1) with respect to time

$$\dot{\rho}(\tau) = x_2 + 2x_3\tau \qquad (2)$$

The epoch, τ_o, is chosen to be the mid-point of the ranging interval.

Equations (1) and (2) are evaluated at τ_o to obtain the following observed slant ranges (ρ) and derived rate ($\dot{\rho}$) measurements:

$$\rho_1(\tau_o),\ \rho_2(\tau_o),\ \rho_3(\tau_o),\ \dot{\rho}_1(\tau_o),\ \dot{\rho}_3(\tau_o),\ \dot{\rho}_3(\tau_o).$$

These measurements are then used to determine the satellite state at the adopted epoch, τ_o:

$$x(\tau_o),\ y(\tau_o),\ z(\tau_o),\ \dot{x}(\tau_o),\ \dot{y}(\tau_o),\ \dot{z}(\tau_o).$$

These trilateration data are obtained 4 to 6 times over the course of a 24-hr day. From each set of measurements, the orbital elements are computed. These sets of elements are combined in a least squares program which then produces a "best fit" satellite state.

ORBITAL PREDICTION

Orbital predictions are generated with the "mean" orbital predictor program developed by the Hughes Aircraft Company. The mean program operates on a set of nonsingular elements to produce a set of osculating elements at a desired time from epoch (τ_o). The nonsingular elements used are:

a semi-major axis,

$e \sin (w + \Omega)$,

$e \cos (w + \Omega)$,

$\sin i \sin \Omega$,

$\sin i \cos \Omega$, and

$w + \Omega + m$

where e, i, w, Ω, and m are the classical eccentricity, inclination, argument of perigee, right ascension of the ascending node, and mean anomaly, respectively.

The prediction process incorporates the Brouwer theory for an artificial satellite (Brouwer 1959), with the only perturbations being the second and fourth harmonics; and a semi-analytic method[2] for computing the changes in nonsingular elements caused by the perturbations by the Sun, the Moon, the triaxial Earth, and solar radiation pressure.

Brouwer theory is used to compute the mean rates of change of the nonsingular elements at τ_o. The semi-analytic method then determines a set of frequencies and coefficients for the expansion

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[2] "Spacecraft Attitude and Motion Control Study," Hughes Aircraft Co., Interim Progress Report, Sept. 30, 1970. NASA Contract NAS 5-21554.

$$\frac{dE_i}{d\tau} = A_i + B_i\tau + \sum_{j=1}^{N} (C_{ij} \cos w_j\tau + D_{ij} \sin w_j\tau) \qquad (3)$$

for each perturbation. E_i, where i = 1, 6, represents the set of nonsingular elements. At $\tau = \tau_o + D\tau$, the change in each nonsingular element from its epoch value is computed by

$$\Delta E_i(\tau) = A_i\tau + B_i\frac{\tau^2}{2} + \sum_{j=1}^{N} \left[\frac{C_{ij}}{w_j} \sin w_j\tau - \frac{D_{ij}}{w_j} \cos w_j\tau + \frac{D_{ij}}{w_j}\right] \qquad (4)$$

The increments $\Delta E_i(\tau)$ obtained for each perturbation are added to the nonsingular elements at τ produced with the Brouwer theory. The osculating elements are then computed from the nonsingular elements at time τ.

Realistic operational tests with the TRRR system did not begin until early December, 1974. Therefore the effectiveness of this system in comparison with that of the STADAN system is still being evaluated.

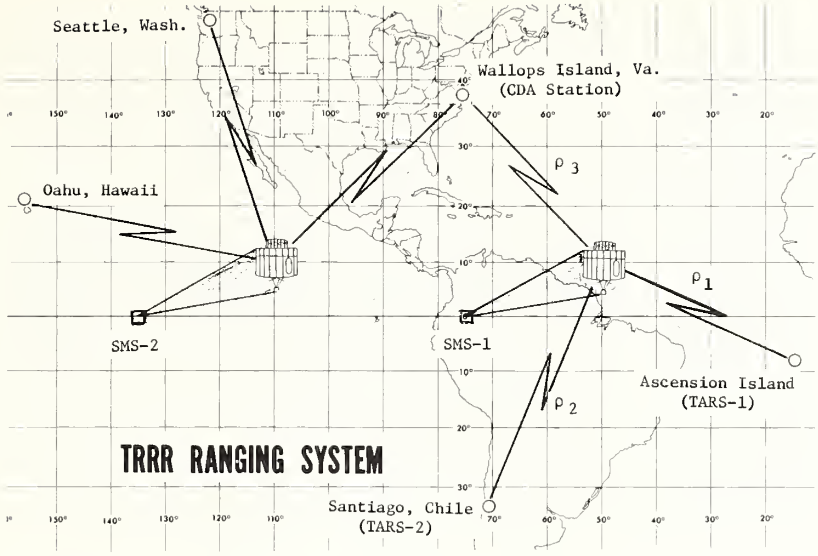

Figure 2-1.--NESS ranging system for SMS/GOES showing triangulation geometry obtained from the Turn Around Ranging Stations (TARS) for the dual satellite system

Figure 2-2.--TARS installation at Oahu, Hawaii. Note the rugged, self-contained design.

3

ATTITUDE DETERMINATION SUPPORT FOR THE SMS/GOES SATELLITES

R. C. Doolittle, J. Ellickson, and J. R. DeMeo

INTRODUCTION

Experimental operations in which ATS image data have been used made evident the need for attitude information from spin-stabilized geostationary satellites. A substantial amount of experience has accumulated in the use of spin scan image data to determine spin axis orientation (roll/yaw components) and the east-west position of the Earth disk within the spin cycle (pitch component). The purpose of this paper is to update an earlier description of this work (Doolittle et al., 1970); current attitude capabilities in support of the SMS/GOES operation are described herein.

One current effort uses image horizon coordinates, another, recognizable landmark features. A somewhat coarser determination scheme for support of early post-launch maneuvers utilizes separate sensors which provide data on the Sun and the edge of the Earth disk. These methods are described in some detail. Star field imaging capability presents an alternate approach, so this, too, is discussed briefly.

THE EARTH HORIZON ATTITUDE PROGRAM

Over the years a variety of in-house efforts to generate attitude information have made use of horizon scan data; problems with ATS image horizon data are discussed in the referenced Doolittle paper. The present SMS Earth Horizon Picture Attitude Determination Program (SMSPIC) is a NESS-modified version of the NASA-supplied ATS Earth horizon digital Picture Attitude determination program (PICATT).

SMSPIC utilizes infrared VISSR horizon data to determine the inertial right ascension and declination of the spin axis. With simple thresholding logic, horizon crossing locations are extracted within the CDA SDB from the incoming IR VISSR bit stream and relayed, together with the image data, to DAPAF via a microwave link. At DAPAF an "EDGE" program on the UNIVAC-6000/6135 computer selects crossing information for 400 scan lines that span the Earth disk, and creates a magnetic tape file containing six picture data sets for use in the attitude determination process. The six selected pictures usually span about

20 hours. The edge tape, orbital elements, and an a-priori estimate of the state parameters are the primary inputs to SMSPIC.

The horizon data contain scan line numbers and corresponding picture element numbers for the left and right Earth edge intersections. Line and element numbers out of range are rejected. SMSPIC converts each scan line number into an equivalent VISSR orientation angle, α, referenced to a plane normal to the spin axis. The edge element locations are converted into left and right equivalent, W_l, W_r, sweep angles from the picture boundary. For each data triplet, α, W_l, W_r, α is considered known. The measurement data, therefore, consist entirely of sweep angles. An ellipse is fitted to the converted horizon data for further editing and to obtain an initial estimate of the horizontal offset. This offset represents the error in spin phase angle, β, in centering the Earth disk laterally with respect to the picture sample domain. Upon completion of this process, SMSPIC predicts the sweep angle from the point of tangency of the VISSR line of sight with the Earth edge to the spacecraft meridian plane bisecting the Earth. Knowing the sweep angle for which the picture is being taken and the β error at the CDA recorder, one can compute the sweep angle from the picture boundary to the Earth edge. SMSPIC uses a Bayesian weighted least-squares technique to minimize the sum of the squares of the difference between measured and predicted sweep angles. The state parameters are differentially corrected until convergence occurs or a maximum number of iterations has been exceeded. At user option, the state vector can also include any principle, geometric misalinement angles Θ and ψ and the effective atmospheric height. Also available is an option to account for β dot errors. Realistic tests of the method were begun late in 1974.

The accuracy of SMSPIC attitude solutions depends upon the accuracy with which the spacecraft location can be predicted, and there is no absolute standard by which to measure its performance. However, the day-to-day consistency in computed attitudes indicates a very high degree of accuracy. During three periods, separated by spacecraft maneuvers, the changes in right ascension and declination were in the same direction and of nearly uniform magnitude, apparently mapping the precession of the spin-axis vector. If one presumes that the smoothed attitude derivations reflect such slow precession of the spin vector, then the small standard deviations obtained would relate to the precision of individual attitude calculations. The following table provides means and standard deviations for the three periods. Thirty-two separate attitude calculations were involved with data missing on one day in the first set and on two days in the second set.

Period (1974)	Spin-Axis Vector Mean Daily Motion (Degrees)	Standard Deviation (Degrees)
November 1 to 13	0.005	0.002
November 17 to 30	.004	.001
December 6 to 13	.003	.001

ATTITUDE FROM SUN/EARTH SENSORS

A family of sensors mounted in a fan configuration provide the means for quick attitude determination during SMS/GOES maneuver operations. The SMS Attitude Determination Subsystem (SMSADS) was developed from an existing attitude program (Interplanetary Monitoring Platform-H Attitude Determination System) prepared for NASA by the Computer Sciences Corporation. It is designed to process Earth and Sun sensor horizon crossing data to determine spin axis orientation in an inertial frame of reference.

Analog Sun/Earth telemetry data are transmitted from the spacecraft to the Real Time Data Unit (RTDU) at Wallops and digitized equivalents are transmitted to DAPAF. The raw digitized telemetry data are written onto a 9-track magnetic tape by the UNIVAC 6000/6135 ingest program. This tape is then used as input to SMSADS on the IBM 360/195 computer. The telemetry data tape contains the following information for each spacecraft spin revolution:

- Frame time
- Frame quality
- Sync pattern
- Sun sensor identifier
- Earth sensor identifier
- Leading edge of Sun to leading edge of Earth (msec)
- Spin period (sec)
- Nutation half period
- Sun pulse width (msec)
- Earth pulse width (msec)

As configured within NESS, SMSADS accepts orbital elements via cards and no interactive device is used. The program, initiated via the card reader, is run in the batch processing mode. Its telemetry processor module reads the telemetry data, converts the data to engineering units where required, checks frame sync, sets appropriate error flags, and provides the user with n-record averaging to reduce data volume.

The main attitude determination program module consists of two major parts: a deterministic processor and a least-squares differential correction routine. In the deterministic processor, each frame of data is processed initially to reject horizon sensor data obtained where the Sun terminator masks the true Earth edge. For each horizon triggering which has not been rejected, two possible deterministic attitude solutions are computed. Once a block of data has been processed, a single attitude is selected from each pair of solutions. The assumption used for the selection process is that the attitude vector chosen should remain nearly constant throughout the block. Joseph and Shear (1972) have developed criteria used in selecting block size. Following the processing of all information blocks, the resulting attitude vectors are averaged. The deterministic processor then uses the selected attitude to compute cone (nadir angle) and dihedral angle data utilizing single and double horizon crossing geometry. These data are then used, together with Sun angle data, in a least-squares differential corrector. The least-squares differential correction routine, GCONES, is described in detail by Werking (1971).

The state vector returned from GCONES may, at user option, include attitude rates and constant biases in the measured observables, in addition to the inertial spin axis orientation. Also provided as an option is the capability of computing data weights for the attitudes selected in the deterministic processor as well as data weights for the cone and dihedral angle data. Data weight computations utilize the uncertainties associated with the observables as specified by the user.

The following assumptions are made in SMSADS:

1. The spacecraft attitude is nearly constant during one spin period.

2. The spin rate is constant during one spin period.

3. The vector from the Earth to the Sun is parallel to the vector from the satellite to the Sun.

A more complete description of SMSADS is given by Botting (1972).

ATTITUDE FROM LANDMARKS

The method of deriving attitude from landmark locations in satellite data has been used routinely in ATS-3 operations. During picture-pair wind extraction operations, this was the primary means for updating attitude. Consequently, it was natural to modify the existing software for use with SMS/GOES. Landmark locations have been obtained from SMS data by using MMIPS (see paper 13 of this memorandum); the resulting attitude is comparable in quality with results from PICATT (described above). With present procedures, however, the cost in man hours prohibits regular use of this process to determine attitude. The geometric principles of the method are described as follows.

Our goal is to compute the negative (or north end) spin axis direction. It is assumed that we know the orbit of the satellite and hence can compute a satellite position for any given time. Since the spacecraft spin axis is nearly fixed in inertial space, we work in that coordinate system. Since each landmark observation is time tagged and its Earth location in latitude and longitude is known, its position in inertial space can be fixed for any given time. We then compute the vector from satellite to each landmark, and derive a direction in inertial space. With knowledge of image coordinates, each landmark now becomes an input observation for attitude determination. With knowledge of the center scan line number, J_c (i.e., the line for which the VISSR is looking out perpendicular to the spin axis), and the angular increment to a scan line, J, which contains a landmark vector, we define the angle $\alpha = 90° - (J_c - J)$ as the angle between the vector to the landmark and the negative spin axis. Knowing α and the direction vector to the landmark, we know that the spin axis must be a member of the locus of directions forming the cone whose axis is the landmark vector. We have such a cone for each landmark observation. Any pair of observation cones intersect, at most, along two lines; we choose the northernmost line. Three or more observations over-determine the system, hence, we seek a least-squares solution using the method of steepest descent.

Once a solution is found, quality analysis is done by using the computed attitude to find picture locations for each landmark latitude-longitude pair, and Earth locations, in turn, are computed for each landmark picture observation. A picture center scan line is also computed. Comparisons may then be made between observed and calculated quantities. A more complete discussion of the mathematics involved is presented by Doolittle (1970).

In practice, the landmark attitude approach is considered a faster means for reestablishing spin axis coordinates following spacecraft maneuvers. With the least-squares fitting of multiple landmarks, one may expect to reduce the number of pictures involved in an attitude computation as compared with the PICATT approach.

Current effort is being directed toward automation of landmark observational inputs. In a manner similar to that described by Simon (1974), we are projecting operational software which will utilize a prestored "dictionary" of cloud-free landmark features. Such a program would select equivalent ambient image sectors using estimated orbit and attitude inputs and develop optimum matching lag coordinates through cross correlation. Coordinate shifts would then be converted into attitude corrections. The basic ingredients of such a software system are now used in picture pair-wind derivations. (See paper 13 of this memorandum.)

PICTURE CENTERING

In navigational parameters, vertical picture centering is a function of attitude, and horizontal picture centering is a function of orbit generation accuracy. To see this clearly, an understanding of S/DB ingest functions is necessary.

As part of the ADAC system in the spacecraft, a Sun pulse and Earth center pulse are determined for each spin revolution. Data transmission timing is triggered by these pulses and synchronized by a 3.5-MHz clock on the spacecraft. One of the major S/DB functions is to model this timing at the ground station. It synchronizes its data reception with its own 3.5-MHz clock by using spacecraft sync words generated for each scan. However, the triggering of data reception, which is equivalent to centering the image horizontally in the data frame, is predominantly a function of spacecraft orbital position. Hence, the computation of the so called "beta" angle (the angle centered at the spacecraft from the Sun to the Earth) is done at DAPAF using a set of orbital elements and a "MEAN" orbital predictor. The basic Sun-spacecraft-Earth angle is generated for a given time and an offset angle is subtracted. The offset is a function of sensor mounting angles, system biases, etc. A time-rate-of-change ("beta-dot") is then computed. A table of beta, beta-dot, and time values is transmitted to the Wallops CDA in two ways: a computer printout listing is mailed weekly and a magnetic tape is relayed via a computer-to-computer link. Centering picture images in this way is a very accurate way of detecting "in-track errors" in the orbital elements. Compensation for these errors is made by adjusting the constant beta offset angle. This is nearly equivalent to adjusting the mean anomaly (spacecraft position at epoch) and is operationally smoother to monitor and control.

Each scan of VISSR data contains two scan numbers: The scan number generated at the spacecraft, which is related to spacecraft geometry, and the image scan count, which is S/DB-generated. The purpose of the latter is to define an array of scan lines that contains a vertically-centered Earth image. This S/DB function is executed by referencing a pre-computed scan line number corresponding to the north-south Earth disk bisector (erroneously named "EQUAT" for equator line). Using this reference line, the S/DB then computes the following limits for the image frame:

North Limit = EQUAT - 836 or 6 (whichever is greater) and

South Limit = EQUAT + 836 or 1821 (whichever is less).

During normal scanning, when the North Limit is reached, the image frame begins with image scan count 1. The image count is incremented until the South Limit is reached. Hence, the EQUAT number centers the Earth disk in the image frame. The VISSR data acquisition computers are programed to ingest only those data within the image frame and sector locations as defined in terms of such image line numbers. So the EQUAT number becomes the vertical centering parameter for sectorizer computer image output. EQUAT numbers are generated on the IBM 360/195 computer using picture start time and spacecraft attitude as inputs. A table of these numbers is produced in the weekly Wallops Acquisition Table and daily on the transfer tape.

ATTITUDE FROM STAR FIELD

Using recognizable star positions in VISSR imagery has been an attractive method of obtaining orbit independence in attitude determination. The inputs to the program are the right ascension and declination and the observed scan line location for each star location. As in the method for attitude determination from landmarks, this information identifies in inertial space a cone that contains the spin axis. The intersection of any three or more of these cones over-determines the spin axis and so a least-squares method is used for the calculation.

Software efforts have involved the preparation of a star ephemeris table and a servicing routine. At this writing, only limited star field acquisitions have been made. More work is needed for preparing operational software for locating and recognizing of stars in the image array, particularly in the presence of random noise. At present, the impact of this capability on operations is unknown.

Since the star image acquisition procedure involves beta offset and VISSR gain change commands, there is a need for extra effort within the control center. Also, for each star image acquisition Earth imagery is denied; thus normal VISSR data utilization is disturbed. Considering orbital independence to be the singular advantage of this attitude determination approach, it may well remain a secondary alternative so long as the more easily used by-product methods described above prove adequate.

CONCLUDING REMARKS

A variety of alternative attitude determination schemes are possible through combinations of some of the methods described above. For example, Phillips (1972) has devised an attitude program that uses horizon and landmark data pairs from a sequence of images. (For a general description of related work at the University of Wisconsin, see the discussion by Sromovsky, 1974.) Alternate algorithms also exist for the generation of attitude from the same data sources. In connection with these algorithms, it is of interest to note that horizon data obtained from the north and south Earth disk grazing scans are eliminated in a preprocessing step by the PICATT program. Paradoxically, such scans are among the richest in terms of information concerning the roll/yaw "tilt" angle for each image. If one could establish such angles using only grazing scans (plus a few adjacent scans), it appears likely that the current ITOS attitude determination algorithm (e.g., see Bristor 1971) would produce results competitive with PICATT. (Some preliminary work by Doolittle indicates the equivalence of the two approaches.) The advantage would most likely be in terms of savings in computer memory space and running time.

In any case, the outlook for attitude support appears bright. With improved automation, we expect to reduce human resource requirements in the landmark approach. Extended operational experience will provide better insight as to achievable precision, but, based upon ATS experience, present levels of precision appear adequate for the support of spacecraft maneuver operations. For image product generation, any need for more precise image alinement information may be based on landmark adjustment as a final step. (See paper 12 of this memorandum.)

4

DATA PROCESSING SUPPORT FOR SPACECRAFT OPERATIONS

L. Jessie, L. Thackwray, B. Sharts, and H. Sparks

INTRODUCTION

Apart from navigational tasks, there are a number of near real-time day-to-day, and occasional tasks carried out in support of spacecraft operations. Command and command verification software support is one such task. Another involves manipulation of housekeeping telemetry data both for CRT display on demand and for post analysis from archival files. A less frequently used program supports spacecraft maneuver and maneuver planning operations. Much of the direct support is provided through a medium scale UNIVAC-6000/6135 computer which accepts inputs relayed directly from the spacecraft by the CDA station and other information relayed through the CDA S/DB. Other support, involving larger collections of such housekeeping data and with noncritical time deadlines, is provided on a large scale IBM 360/195 computer system. This paper gives an overview of these support programs in the context of their operational utilization.

DIRECT HOUSEKEEPING DATA SUPPORT FOR SOCC

Four CRT/Keyboard terminals within SOCC provide the interface for direct support from the UNIVAC 6000/6135 computer system. Several processor programs make up the processing system which operates under the control of a general scheduler program. The functions and patterns of usage of the several processors are described below.

Telemetry. The SOCC Controller loads the telemetry processor on request from the scheduler. Telemetry information is transferred to magnetic tape for archiving and for on-line use. Normally such information is extracted from only one incoming data frame out of a sequence of 32 frames, but a switch option permits saving all data. By search within the program, telemetry frames that contain command verification are also extracted automatically. On request, the controller may obtain complete line printer output, or he may display, selectively, any of 25 groups of telemetry on the CRT. Each group may contain up to 25 individual items. The items within each group are preset and contain information on a particular subsystem.

Events. When called up, this processor displays ground station conditions on the CRT terminal. Option exists to display any of seven groups of items on any of the available CRTs. This program interacts closely with the telemetry processor; it displays commands as transmitted to or as received by the spacecraft, and the times of execution of all commands.

VISSR IR Ingestion. Upon demand from the SOCC Controller, 8- by 8-km data relayed from the CDA via microwave link may be ingested and stored on magnetic tape for horizon point extraction or for other quantitative processing.

Sun/Earth Processor. Approximate assessment of spacecraft attitude may be obtained by display of data from the separate Sun/Earth sensor package. This processor displays resulting attitude information on CRT or line printer. Information is also stored on disk for post analysis and archiving.

Trilateration Data Acquisition. This processor ingests the range and range-rate data used in later trilateration and orbital determination by a navigation software run on the IBM 360/195. The information is stored on disk and may be retrieved upon request from the SOCC Controller.

MANEUVER SUPPORT

Assistance in maneuver operations is a continuous closed loop process. The process segments include data collection and analysis, maneuver planning, maneuver implementation, post-maneuver evaluation, and a return to data collection and analysis to continue the process.

Data collection and analysis provides evidence of the effects of perturbing accelerations including those resulting from natural causes (solar radiation pressures) and those resulting from ground commands. Spin axis orientation, spin rate, and orbital parameters (elements) are monitored in this process. Trends are monitored for each. Maneuver planning is initiated on the basis of projections of times when previously imposed limit values will be reached. The maneuver planning program "SMSMAN" is run to obtain quantitative information for several maneuver options for consideration by spacecraft control management.

With multiple jets capable of generating torques in all three spatial dimensions, there is a definitive need for spacecraft maneuver planning support. Spin stabilization further complicates the maneuver operations because lateral jets must be pulsed within precise time windows to obtain a desired net torque. Total force generated by a series of pulses is also critically dependent upon highly precise jet thrust calibration. The maneuver system and the supporting software model are described in several NASA contract report documents (Rochkind, 1973, 1974, and Bishop, 1973); details of jet calibration techniques are described by Bishop and Moore (1974).

The SMSMAN program can be used for a large class of spinning satellites; it computes the maneuver scenario and requisite ground station commands for the following six maneuvers:

1. Axial jet spin-axis reorientations,

2. lateral jet spin-axis reorientations,

3. pulsed radial jet delta-V east-west station keeping (drift change) maneuver,

4. continuous lateral jet spin change,

5. axial jet delta-V, and

6. axial jet north-south station keeping (inclination and node longitude change)

The output data that describe the entire spacecraft state during the maneuver are separated into a maneuver requirements table, a signal table, a calibration table, and an orbit and spin table. A "command" printout sheet is also produced for each station. Other related programs available for maneuver planning support give requested data on solar eclipses, lunar conflicts, subsatellite coordinates and other orbital prediction products, communications acquisition (pointing angle) tables for each station, and results of east-west drift calculations.

Once management decisions are made as to desired satellite station positions, and policy decisions have been reached on allowable off-station drift and deviations in attitude and spin rate, then the SOCC navigator, using the program output described above in combination with past trend data, makes his projections. On the basis of these projections, he determines times when established limits will be reached. From the corrective maneuver options provided, a command plan is selected and implemented so that disruptions to operations will be minimal.

The procedure may require that a number of program calculations be rerun to optimize the precise maneuver sequence needed to achieve the desired result. The combination of thrust commands finally established is chosen so the objective will be achieved with minimum consumption of jet propellant.

When the plan becomes a part of the operating events schedule (at least 24 hours before execution), a message is sent to the SOCC and to the CDA crews for review and coordination. The plan receives a final review by both units shortly before execution, and all applicable equipment is configured for the maneuver. Finally the commands are executed at the direction of the SOCC Controller.

In the 24 hours following the maneuver, ranging data are obtained for updating orbital elements. VISSR imagery is utilized to reevaluate attitude, and telemetry checks on spin rate are also made. When the data collection and analysis are complete, a full evaluation can be made of the maneuver. Normally, after the maneuver is declared satisfactory, the routine collection and analysis of trend data for the eventual planning of the next maneuver is resumed.

5

EARTH LOCATOR GRIDS FOR VISSR IMAGES

J. Ellickson

INTRODUCTION

Earth locator grids for ATS geostationary satellite imagery were first developed in 1967 (Whitney, Doolittle, and Goddard 1968). Although grids were automatically combined with the images on an experimental basis, difficulties in reliably centering the Earth disk within the digital image array prevented the mounting of a routine operation. Families of separate computer-produced grids were provided for hand melding operations. Many options and diagnostic features were added to the software to improve the precision and eye appeal of the grids and to eliminate the need for retouching and hand labeling operations. With the advent of the new IBM 360/195 central computer facility, it seemed proper to make a new beginning rather than to convert the existing complex software.

This paper describes a new picture grid program that evolved from a NESS contract project in support of the GOES mission. Many options are provided for the production of hand meld grids on film and for the generation of computed tables of grid point locations. These tables are relayed by DAPAF to the CDA stations for automatic melding within the S/DB. An overview of this new gridding capability within the framework of the GOES operation is described herein. For a more complete description, the reader is referred to the Gridding Project Final Report (1974).

BASIC GRIDDING SOFTWARE PACKAGE

The basic function of gridding is computation of picture image line scan and sample (x,y) locations, using as input a set of Earth-located latitude-longitude grid points. The problem is best described as having three major parts:

1. Creation and maintenance of a collection of files containing grid point definitions,

2. Computation of image coordinates from the above files, and

3. Formatting the output for use in various applications.

In designing the gridding files, two important structural qualities, accessibility and efficiency, are desired. Accessibility provides the flexibility to handle unforeseen applications, modifications, or updatings; efficiency is needed to handle high volume processing in minimum computer time. The result is seen in figure 5-1.

For this discussion it is convenient to define the following terms. A "feature" is a series of grid points that form a line segment. Features are the smallest accessible groups of points in the structure, e.g., a lake or island outline. The "Master Feature File" (MFF) contains all features used by the system with the exception of latitude and longitude lines which are generated independently and are stored in the "LAT/LONG" file.

The MFF was originally generated from a magnetic tape file developed by the U.S. Air Force. It defines features such as coastlines, international political boundaries, U.S. State boundaries, large lakes, and islands. Each feature has been labeled as to general category by the use of a bit setting of two special "qualifier words" which accompany the feature through the processing. These bit settings are defined in the "Vocabulary File."

Features can be easily added, deleted, or modified, but are not filed in any recognizable geographic order in the MFF. An Earth Reference File (ERF), organized by Marsden Squares, has been created to provide easy access to features in the MFF. Grid points are processed only within Marsden Squares that are within the viewed field. They are stored in a working file called the Intermediate Output File which is accessible from the main gridding program. Features can be added for one-time processing by using the "Auxiliary Features File." Characters and symbols for use as picture annotation also can be added to the MFF. This file structure provides the necessary flexibility for grid calculations.

The Gridding Algorithm (GA) writes the "Low Density Grid File" which, in turn, is processed for a particular application. The GA is the main program module in the entire software package. There are separate GA's for "spin-scan" type geosynchronous satellites such as SMS/GOES, and for polar orbiting satellites such as those in the ITOS/NOAA series.

Processing for SMS gridding proceeds as follows: An "Ephemeris Table" is generated for the time period of the picture to be gridded. This table contains satellite locations, change of coordinate system matrices, and other time-oriented information.

Next, the input files are read and each feature is processed. For each grid point, an observation time is generated and the corresponding satellite location is used to compute a vector direction to the gridpoint, which in turn is converted to the scanner coordinate system. When locations have been computed for all grid points in the feature, they are written out to the Low Density Grid File, which is then available as a source for generating grid products in several output formats.

GRID OUTPUT PRODUCTS AND APPLICATIONS

There are two general types of gridding applications: "Hand meld" and "Automatic." Hand meld gridding of SMS imagery is the placing and fitting by hand of a clear film grid template, with gridding information photographically added, over an image. The result is a gridded picture in which the precision of Earth location is a function of the accuracy of spacecraft-Earth position inputs to the gridding software and the expertise of the human technician in alining the template.

The gridding system produces film overlay grids as follows. The pairs of stepping-sweep angles in the Low Density Grid File are converted to picture raster coordinates by using the input parameter center scan line, center sample number, angle between lines, and angle between samples. The raster coordinates are sorted and a DMD tape is written. The tape is then displayed on a DMD and a clear film overlay grid is produced photographically.

Since the orbit is not perfectly geostationary, a library of overlay grids is produced for each spacecraft. A set of subsatellite point grids is prepared usually for 1/2° intervals both east to west and north to south of the nominal subsatellite point. The number of longitude steps needed is a function of orbit eccentricity and daily drift, while the number of latitude steps used is a function only of orbit inclination. In the case of SMS-1, with a nearly 2° orbital inclination, extra grids are needed for 2°, 1.5°, 1°, and 0.5° both north and south. At present, overlay grids are produced to fit all NWS standard sectors. For example, while the satellite is on station at 75°W, grids are produced for the full disk, for one 4-km sector, for five 2-km sectors, and for thirteen 1-km sectors. Each of these sectors can be displayed on either of two display devices. Considering the number of sector areas, and the number of possible subpoints, a large number of computer runs are needed to generate an operational library of grids for each station of a single satellite.

Automatic gridding represents another primary production mode. In this mode the output program produces a magnetic tape formatted for the S/DB at the Wallops CDA. This tape consists of a "Setup" file, containing calibration tables and an index of the tape contents, and a variable number of "picture files," each containing gridding information. The computer-produced tape is transmitted to Wallops by a tape-to-tape minicomputer "Grid Transfer System" over a C-5 telephone line.

At the beginning of each day, a precalculated grid tape is mounted on the S/DB and used to initialize system parameters. For each picture so selected, the gridding information is read into the computer and merged with the IR data by the addition of a "ninth bit" to each 8-bit IR sample. Gridding information bits thus become a part of the stretched VISSR signal. Retransmitted data received at Suitland, Md., are recorded on digital magnetic tape and on photofacsimile imaging recorders. During this process the ninth bit is stripped off and used to generate gridding tables, one for each IR scan line.

A selector switch at the display device governs the automatic melding of grid bits into the image product. Figures 5-2 and 5-3 show examples of images with automatic gridding.

Apart from the two major application outputs described above, there are secondary uses for gridding software. For use at facsimile or WEFAX receiving stations that have display devices with different aspect ratios, one may transmit just the grids. These grids, received on station equipment, assume shapes compatible with imagery received on the equipment and so can be used as hand meld grids.

Hand meld grids are also produced in support of a variety of communications and geographic image coverage investigations.

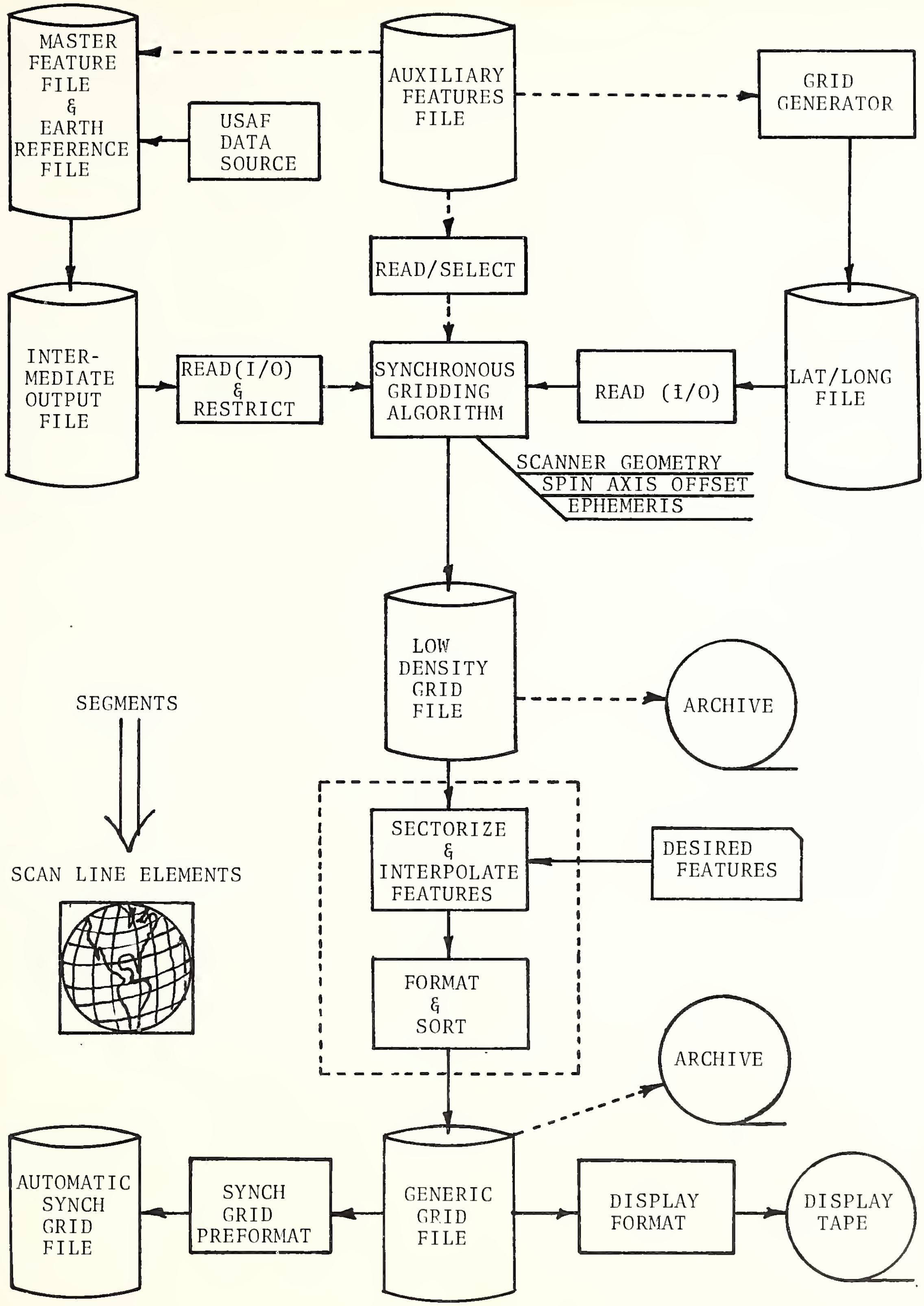

Figure 5-1.--Design overview of VISSR image gridding program

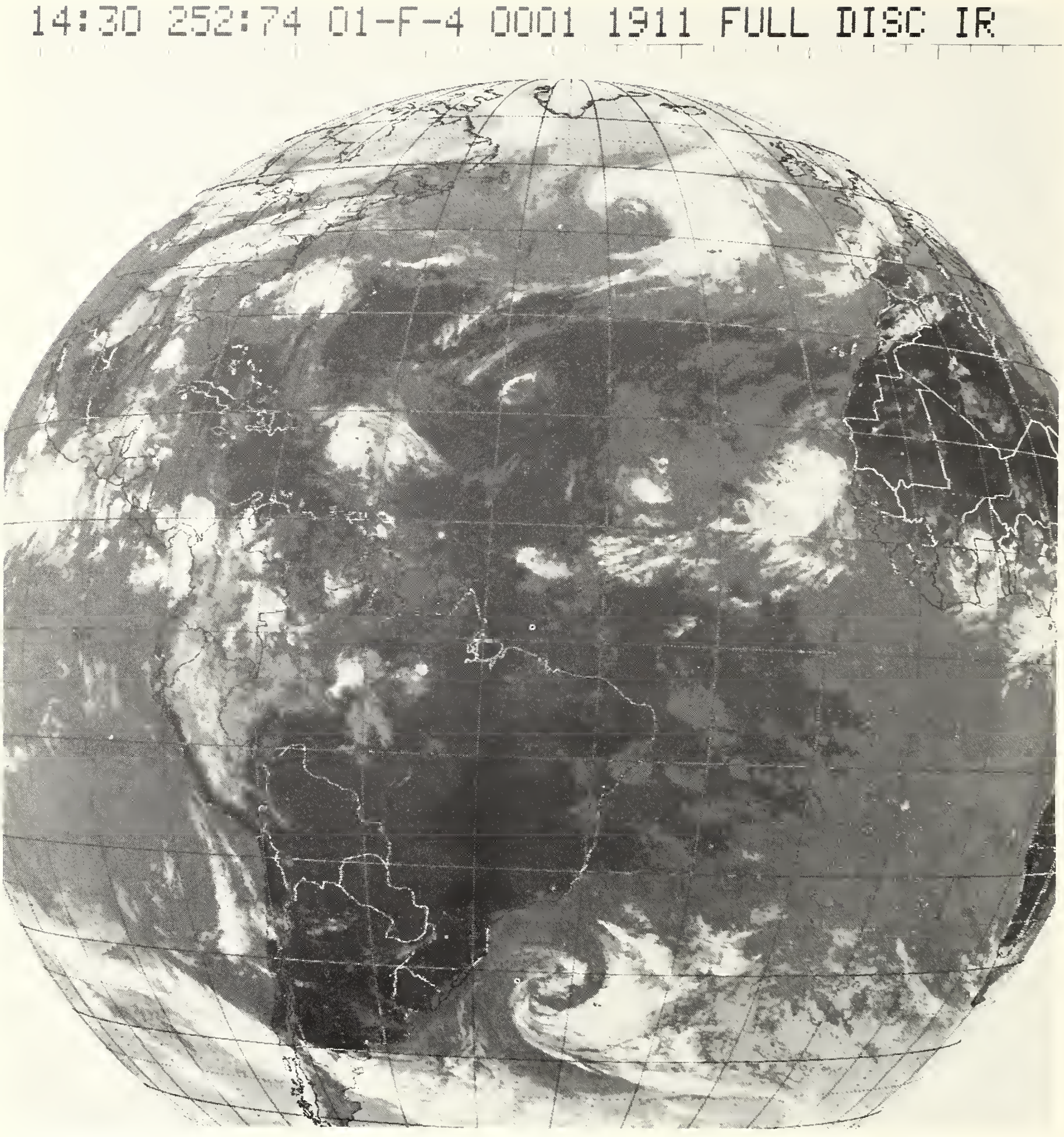

Figure 5-2.--Latitude-longitude grid automatically melded with a full disk IR GOES image

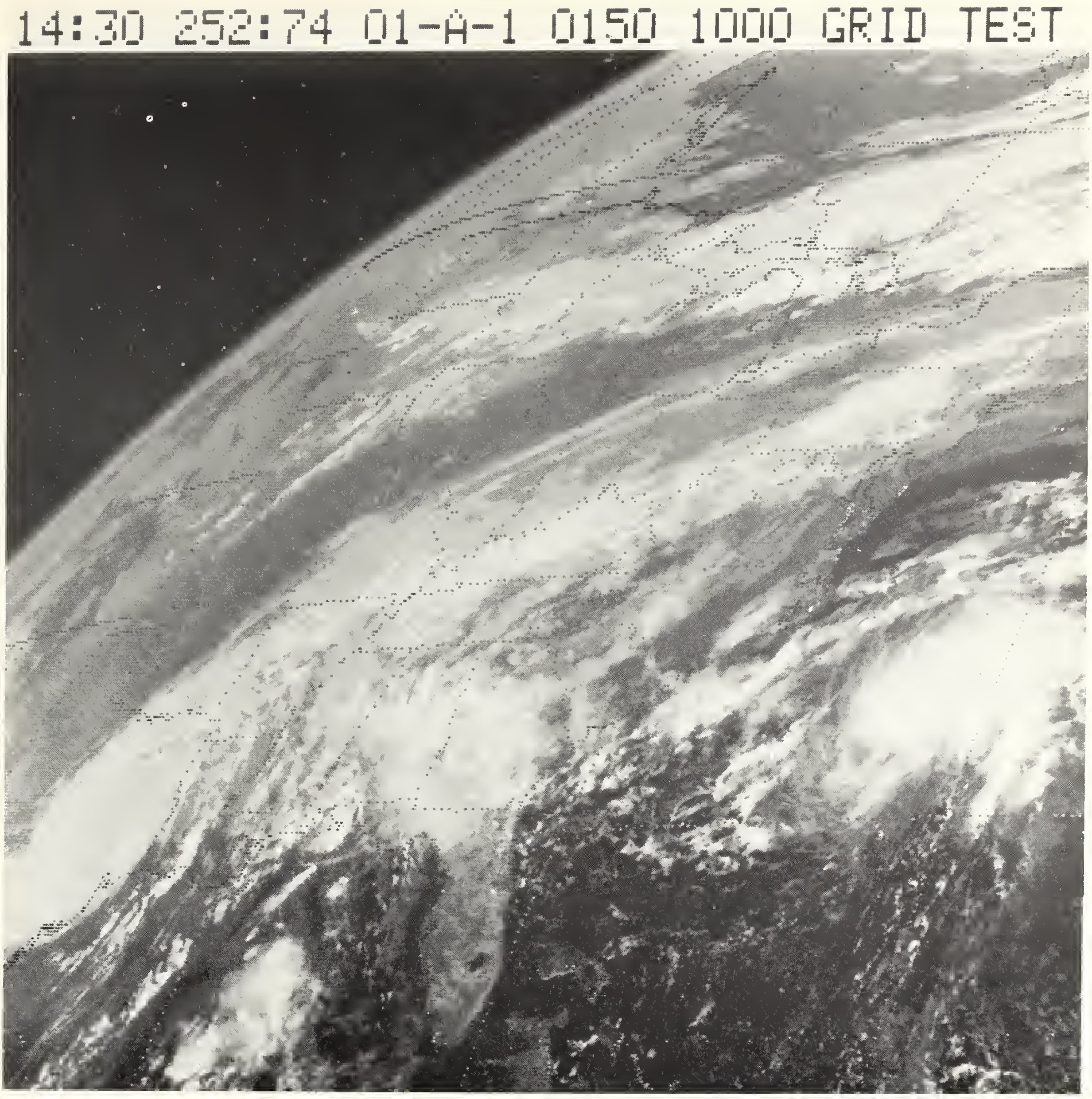

Figure 5-3.--2-km visible channel GOES image sector with automatically melded grid

6

OPERATIONAL MAPPING OF VISSR IMAGERY

M. Shellman and R. C. Doolittle

INTRODUCTION

An earlier report describes an ATS-1 image mapping experiment that began in mid-1969 (Bristor and Lauritson 1970). Routine production evolved from that experiment and scheduled transmissions of Polar Stereographic and Mercator mapped imagery were made via WEFAX until the ATS-1 spin scan camera became inoperative on Oct. 16, 1972. Limited production of mapped images was also carried out for ATS-3 after software was revised to accommodate a spin axis offset. A more generalized mapper program has evolved from these earlier efforts. The current VISSR data mapping operations and the software involved are described herein.

THE EARTH LOCATOR ARRAY

The basic approach to image mapping begins with earth location precalculations for an open lattice of image "benchmark" picture elements. Inputs to these calculations include the line and sample (x,y) coordinates of the picture elements plus all information needed to transform these coordinates into latitude-longitude equivalents. Primary elements required are imaging time, orbital elements, attitude, radians per sample, radians per line, and other pertinent details, such as possible offset in telescope mount.

The computer program that calculates the earth locator array obtains the needed inputs from two data sets prestored on disk. One set contains orbital elements and attitude and the other set contains picture time and image geometry parameters generated during the loading and preprocessing of the raw VISSR image. For a given instant, corresponding to the time when the selected picture element is sampled, the calculations first establish the orientation (pointing angle) of the telescope in terms of an orthogonal coordinate system referenced to the spacecraft. With orbital inputs and time specifying the precise location of the spacecraft, a transformation to geocentric coordinates relates the pointing angle to the Earth, thus translating the original picture coordinates into latitude-longitude equivalents. Where necessary, calculations are carried out in double precision so that the equivalence between x,y and latitude-longitude pairs is essentially a function of the quality of input information.

In the present operation where 4- or 8-km resolution VISSR data are mapped, the open lattice benchmark calculation is made for every 16th sample of every 16th scan line. Calculations for the 15,000 benchmark points requires about 20 seconds of CPU time on the IBM 360/195. The time for calculating an earth locator for each individual picture element would be prohibitive. The boundaries for the open lattice calculations are preset by a computation based upon the known field of view and selected limits for the realm into which image data are to be mapped. In order to maintain a generalized service, the benchmark calculation is terminated at this step. Once a map projection is selected, decisions must be made concerning a new grid mesh into which the resulting mapped image elements are to be stored.

THE MAPPER PROGRAM

With the GOES dual spacecraft system we now have opportunity to produce mapped imagery for a vast area on a truly synoptic basis, discounting the likelihood of small differences in picture acquisition time (perhaps 15 minutes). Figure 6-1 shows the Mercator mapper area covered by data from the two-spacecraft system. A specimen of mapped SMS-1 imagery is shown in the right half of the figure and the raw VISSR source picture is shown as an inset in the western portion of the map area.

Since meteorological interests prefer information depicted on polar stereographic or Mercator maps, program options exist for image mapping in either projection. With VISSR scans alined approximately with standard Mercator maps, the mapping program operates more efficiently for that projection.

The mapping algorithm might be called a direct system because each raw data scan is processed in sequence and transferred directly to the map array storage buffer. Presuming the Mercator projection is selected, the first step is the selection of a fine mesh, orthogonal map array grid into which selected raw picture elements will be moved to create the mapped image. For Mercator mapping, a square mesh with 11.25 storage elements per degree of longitude is alined with the Equator and the map meridians. Using this new map grid, with an i,j coordinate system in our map projection equations, the open lattice benchmark latitude-longitude locations are transformed into equivalent i,j coordinate values. Calculation of the map storage locations for sequences of input scan elements is now in order.

The preprocessed input data are available on a disk file together with scan line identifier and other documentation. Either 4-km visible-channel data or 8-km IR data may be selected. Since the computer deals more effectively with 8-bit samples, the 6-bit visible-channel elements are adjusted to occupy 8 bits. Software from that point onward may then treat all picture elements in like fashion. Knowing the line and sample x,y locations of the benchmark points, we now bring in a convenient number of lines of raw scan data, starting with the first line that lies within (or bounds) the benchmark array. At this point, the three necessary ingredients on which the mapping algorithm can operate are present: scan sequences of input data samples in a 4-km or 8-km x,y array, a related i,j map storage buffer array of 11.25 mesh per degree (approximately 8-km resolution), and tables of precalculated i,j values for a selected open lattice of orthogonal x,y image points with 16 x 16 raw picture element spacing.

For a selected input data scan sequence, a question is now asked: Is this a preselected scan (y value) for which i,j benchmark values have been computed? If not, the values from bracketing benchmark rows are used to interpolate j values for this y scan row. In either case j values are available for the subject input data scan. If j interpolations are required, companion i values are also interpolated so that an open array of i,j's is now available for the raw scan data being mapped. The data are then moved to the map storage area by interpolating an i,j storage address for each element in the input scan sample string. This process is repeated for each scan of input imagery until the benchmark file or the picture data source is exhausted. The mapped image array in main memory is then moved back to its allocated space on disk. To control memory needs, the mapper program benchmark array is subdivided into modules. The above process is, therefore, repeated until all benchmark modules have been exhausted.

The key to program efficiency is the central interpolation algorithm. To map imagery, even on a large computer, the interpolative generation of map storage addresses must be vastly superior in running time to the coordinate transformation approach used in the open lattice calculations. If the benchmark array is sufficiently dense, i,j address coordinates can be generated with a simple linear interpolator. And if the open array interval is a binary factor (power of 2), interpolations may be accomplished with shifting logic rather than with arithmetic multiply instructions. For Mercator mapping, such an interpolation routine has been produced in IBM 360/195 machine language to achieve maximum efficiency.

The mapping program (including input and mapped output data buffers) requires 425,000 bytes of main memory; a typical mapping job requires about 1.25 minutes of CPU time. The map array consists of 1302 storage rows with 1913 picture elements per row. A preprocessing program, mentioned earlier, must also be run for each raw VISSR picture. Among other tasks, the preprocessing program transfers the raw picture to disk and establishes overall correspondence between Earth-disk-image line and sample positions and latitude-longitude positions. Although the 5 minute CPU run time for this program represents an overhead penalty, it is shared with picture wind estimations and other missions. Once the mapping process is completed, the 1913 x 1302 sample array resides on computer disk as a source for display products or for further quantitative information extraction. Such follow-on activities are discussed elsewhere in this memorandum.

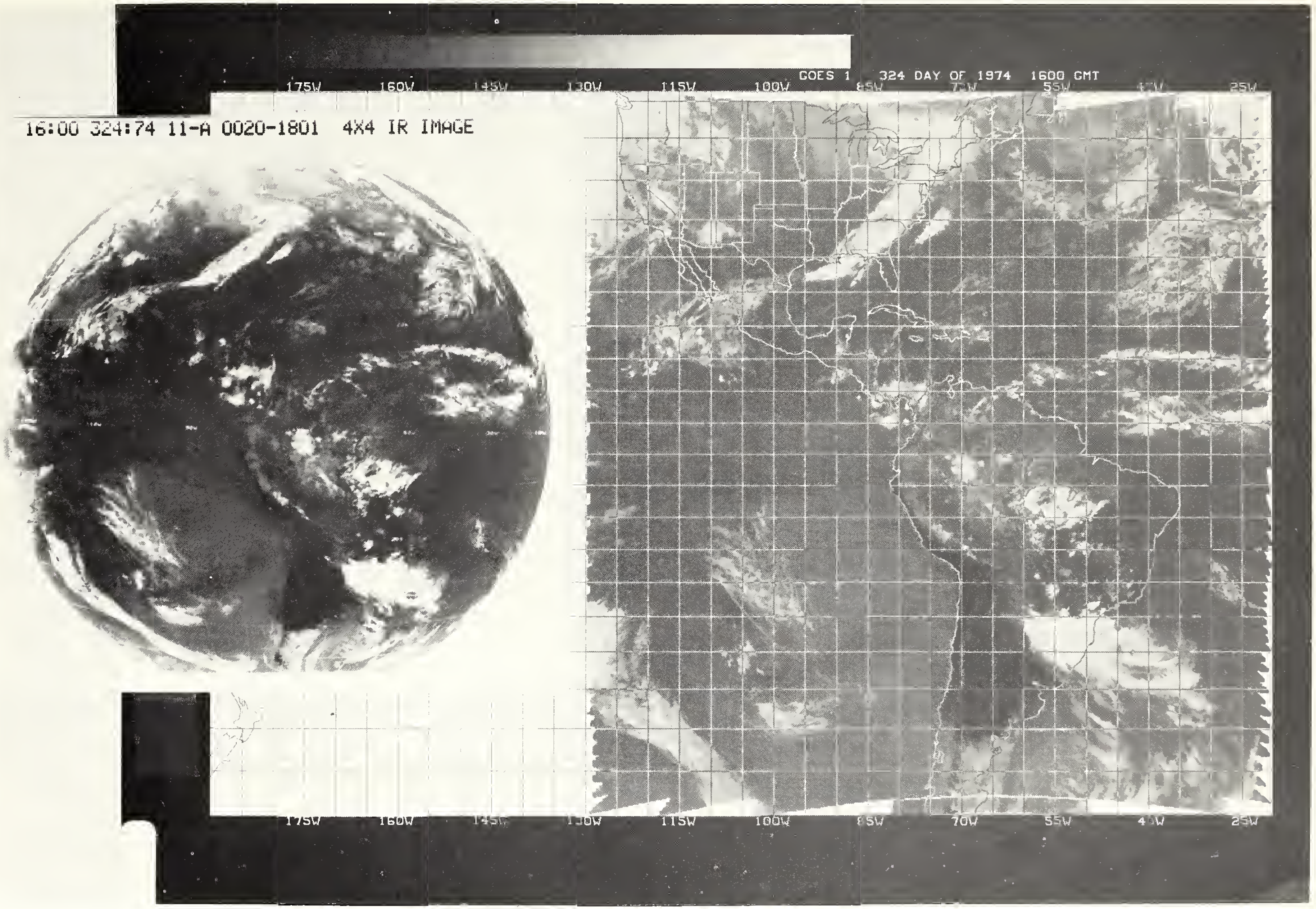

Figure 6-1.--Mercator-mapped SMS-1 IR image (right) and unmapped source image (left inset). An overlapped image from the eastern Pacific spacecraft would normally fill the unmapped region.

7

DIAGNOSTIC TOOLS FOR QUALITY ASSESSMENT OF VISSR DATA

B. Goddard and B. Remondi

INTRODUCTION

A diversity of diagnostic tools are needed to mount a successful image data processing operation. One class of diagnostics provides on-line checks at the various processing stages, and, where critical limits are exceeded, normal processing is interrupted. In checking the acceptability of incoming raw data, the diagnostic action should take place at the earliest possible point in the processing sequence to minimize resource investment and to maximize opportunity for alternate recovery action. Other diagnostics are integral portions of the data handling process as, for example, where calibration processing provides averaged reference levels for the transformation of raw digital response into calibrated values. Outputs of such steps are often accumulated to monitor long term trends. In some cases processing segments contain optional diagnostic routines which may be invoked manually or triggered automatically by some performance threshold test. Still other diagnostic packages may run as separate programs to make periodic checks.

Apart from their direct contribution to the calibration process, diagnostics provide insight and have impact in other ways. Geometric stability of image arrays can be assessed both in terms of line-to-line jitter and in terms of longer period image skew. Noise content can be measured in terms of overall magnitude, relative coherency, and spatial frequency distribution. Histograms and related diagnostic tools also assist in tuning display lookup tables for interchannel balance and in maximizing display effectiveness. Longer term sensor response trends may also be monitored.

A hierarchy of diagnostic tools has been developed over the years. Our purpose is to describe several diagnostic tools currently in use and to indicate the role each plays in the GOES operation. Our emphasis is on those routines which fall in the stand-alone category. Others, which are incidental to the various processing activities, are discussed elsewhere in this combined memorandum.

HISTOGRAMS

Simple frequency distribution (histogram) displays have proven to be one of the most valuable of the diagnostic tools used in monitoring satellite image data. In the case of ATS spin scan imagery, such routine plots (Doolittle et al., 1970) provided insight on the performance of the analog-to-digital converter, the level of noise (particularly in spaceview response, stability, and proper adjustment of the frequency modulated signal discriminator), and long term trends in image sensor-photomultiplier response. Experience has shown that the meteorological scene variability remains as only a minor contaminant if one uses a full Earth disk plot for checking day-to-day stability and other broadscale response characteristics.

A cursory inspection of the histogram shown in figure 7-1(A) reveals the following:

1. Using nearly 5 million full Earth disk IR samples (8-bit bytes), response is distributed so as to adequately utilize the 0-255 count range.

2. Apart from voids (characteristic of the fixed point algorithm required in the real-time transformation of raw counts into calibrated values), there appear to be no serious odd-even biases or other problems in the digitizing process.

3. No signal "clipping" is observed at the warm (low value) end.

4. Noise content is very low--as indicated by lack of dispersion around the cold space response (254 value).

In the past, histograms of the differences of adjacent sample pairs have revealed artificial nodes symptomatic of digitizer flaws. The companion difference histogram in figure 7-1(B) contains only a faint suggestion of such difficulty. (Note the small cluster at -157 and +157.) Otherwise, with overlapped sampling, one notes the substantial symmetric peak at zero difference.

In the case of visible channel data, histograms provide an excellent means for comparing responses among the eight photomultipliers. Such a set of distributions of 1-km data is shown in figure 7-2. Each contains 600,000 samples in an image sector covering a Caribbean hurricane. With lookup table logic in the S/DB set at one-to-one equivalence, the plots represent direct VISSR output except in the case of channel seven. Because of channel seven failure, channel six output has been redundantly configured as channel seven output to avoid image streaking. Although all plots show strong similarities, there are differences--particularly noticeable in the dark (low value) cut-off level. A slight tendency toward a bias in the odd sample values (e.g., values 33, 39, 41) is also noticeable. This slight indication appears to be an attribute of the digitizer because all channel signals pass through a common conversion pathway.

Other types of histogram presentations are, of course, possible. Earlier experiments with ATS imagery suggest the use of two-dimensional histograms in which frequency isopleths are constructed on the basis of orthogonal pairs of arguments. One such experiment combined the two arguments shown in figure 7-1(A) and (B). As a result, artificial difference nodes seen to cluster at specific absolute value levels reveal the nature of digitizer problems more clearly. Composites of noisy cases contrasted with noise-free cases further revealed the sensitivity of the data handling system to fluctuations in the ATS analog signal near particular value levels. Although histograms have thus far revealed only insignificant imperfections in the VISSR signals, some interest remains in multiargument histograms; here isopleths showing the pattern of coincident visible and IR occurrences offer one possibility.

Apart from the problem in visible channel seven, mentioned earlier, image streaking also occurs with only slight response variation. Unfortunately, much of this subtle variation tends to be masked in histograms such as figure 7-2. Therefore, present display lookup tables using statistical parameters have been generated. Variance and mean values calculated from portions of 1-km visible lines have been particularly useful in determining normalization tables for minimum streaking.

NOISE AND SPECTRAL ANALYSIS

Systematic noise is typically detected through spectral analysis; such a tool is available for use with VISSR data. Figure 7-3 shows a plot of a hundred-line sector of 1-km visible channel data containing 1,024 samples per line. The meteorological scene, selected because of its homogeneity, is composed mainly of stratocumulus cloud fields off the west coast of South America. In contrast to ITOS spacecraft-recorded scanner data (Conlan 1973), the plot appears to be essentially free of measurable coherent noise. A number of such plots, using both visible and IR channel data, have all produced similar results.

The presence of random noise in the VISSR signal is more directly measured by a noise reporting scheme designed into the spacecraft. True random noise appears as "salt and pepper" in visual image samples, but experiments in which random noise is added in varying amounts demonstrate the inadequacy of visual monitoring (Danko 1972). The quantitative monitoring facility used employs fixed bit patterns in sync words combined with and transmitted as a part of the VISSR signal. Within the S/DB, such bit patterns are compared with their known counterpart and a "word" error rate is produced for each scan. Since this information is included in appended documentation with the rebroadcast VISSR data, it is readily available for quantitative monitoring at Suitland. In DAPAF the word error rates for hundred-line groups are summed and converted to an equivalent bit error rate. A typical bit error rate diagnostic print-out is shown in figure 7-4. This record from SMS-1 was obtained on December 27, 1974, when only three of the four transmission system power amplifiers were operating.

OTHER GRAPHIC TOOLS

Direct digital printout of limited sample arrays is sometimes very informative, but less quantitative visual tools often provide first-step insight to the need for other diagnoses.

Simple image enhancement by special lookup table can often be very useful. Figure 7-5 is an example which provides insight as to behavior of the VISSR optics when looking at the Sun. Visible channel normalization table needs can more easily be determined and the presence of occasional coherent noise patterns can also be noted using enhanced images (fig. 7-6).

Another handy tool is a line profile plot. Figure 7-7 shows an example of an IR scan. Combinations of a line profile plot of enhanced image sectors with selected line profile "cross section" plots often complement each other. For example, in selecting a proper response value as a horizon crossing discriminant, one must avoid artificial triggering by noise spikes and yet maintain discrimination in the steepest slope domain. Such graphic displays provide valuable insight for making such selections.

CONCLUDING COMMENTS

The foregoing comments are brief descriptions of several "stand alone" diagnostic tools. The algorithms involved are basically straightforward mathematical and statistical routines coupled with convenient pictorial or graphic output. Thus far, only very minor VISSR performance flaws have been revealed. The SMS/GOES system was still new at the time this was written, so not all of the appropriate diagnostic tools had been developed. In other sections of this memorandum, there are comments about items included as documentation in the signal bit stream emanating from the S/DB. Trend plots and other graphic treatment of these items will doubtless prove useful both for data quality diagnosis and for SOCC support. Design lifetime of the GOES spacecraft is nominally five years, but, typically, the operation of early spacecraft in each new series tends to uncover any weaknesses in design, materials, or fabrication. We therefore expect that development of most diagnostic tools will occur within the next few years. Once the system matures, certain diagnostic procedures tend to become standardized and the need for new tools diminishes.

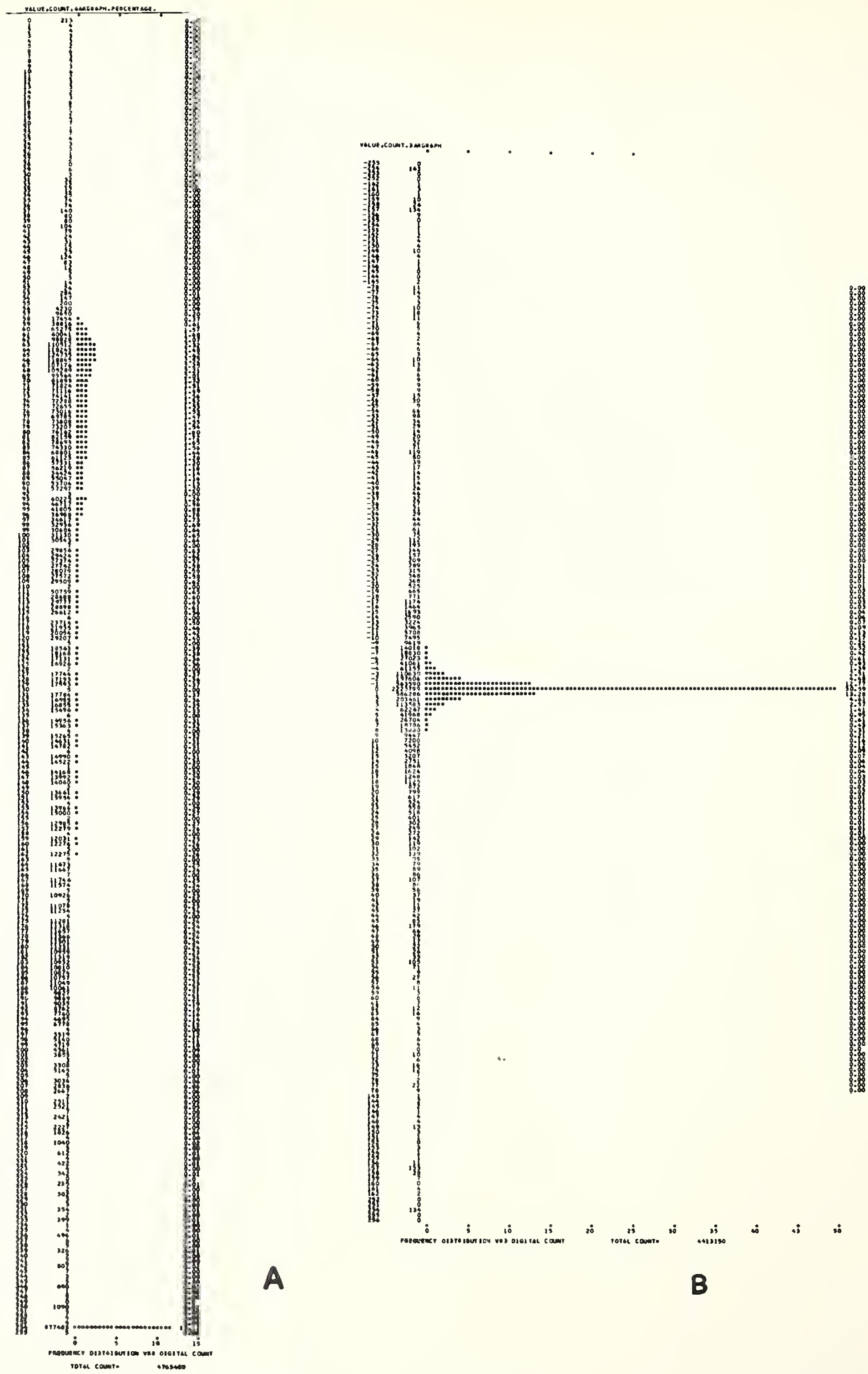

Figure 7-1.--Histograms showing: (A) the distribution of temperatures coded in a 0-255 value range for a full Earth disk IR VISSR image, and (B) the related histogram of differences of adjacent sample pairs. Each asterisk represents 0.5% occurrence. The (B) profile has been truncated in areas with only a few occurrences.

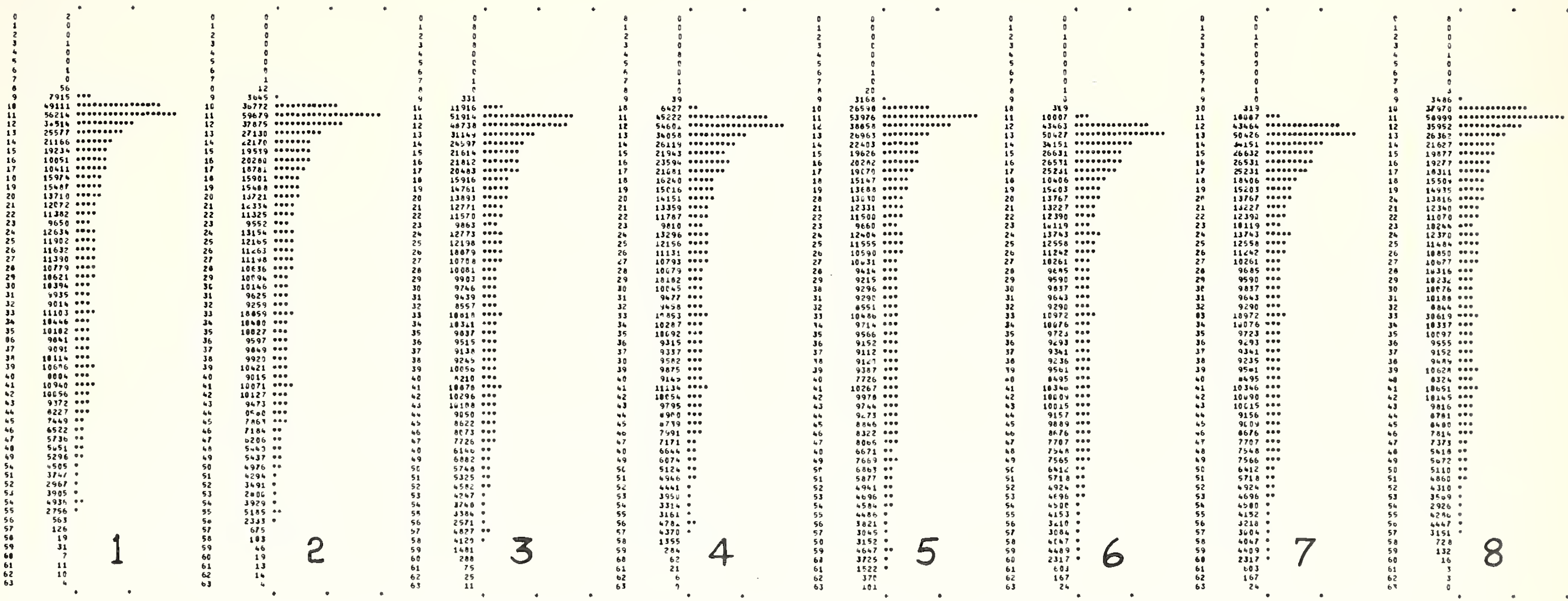

Figure 7-2.--Histograms for the visible channels showing response differences between photomultiplier outputs

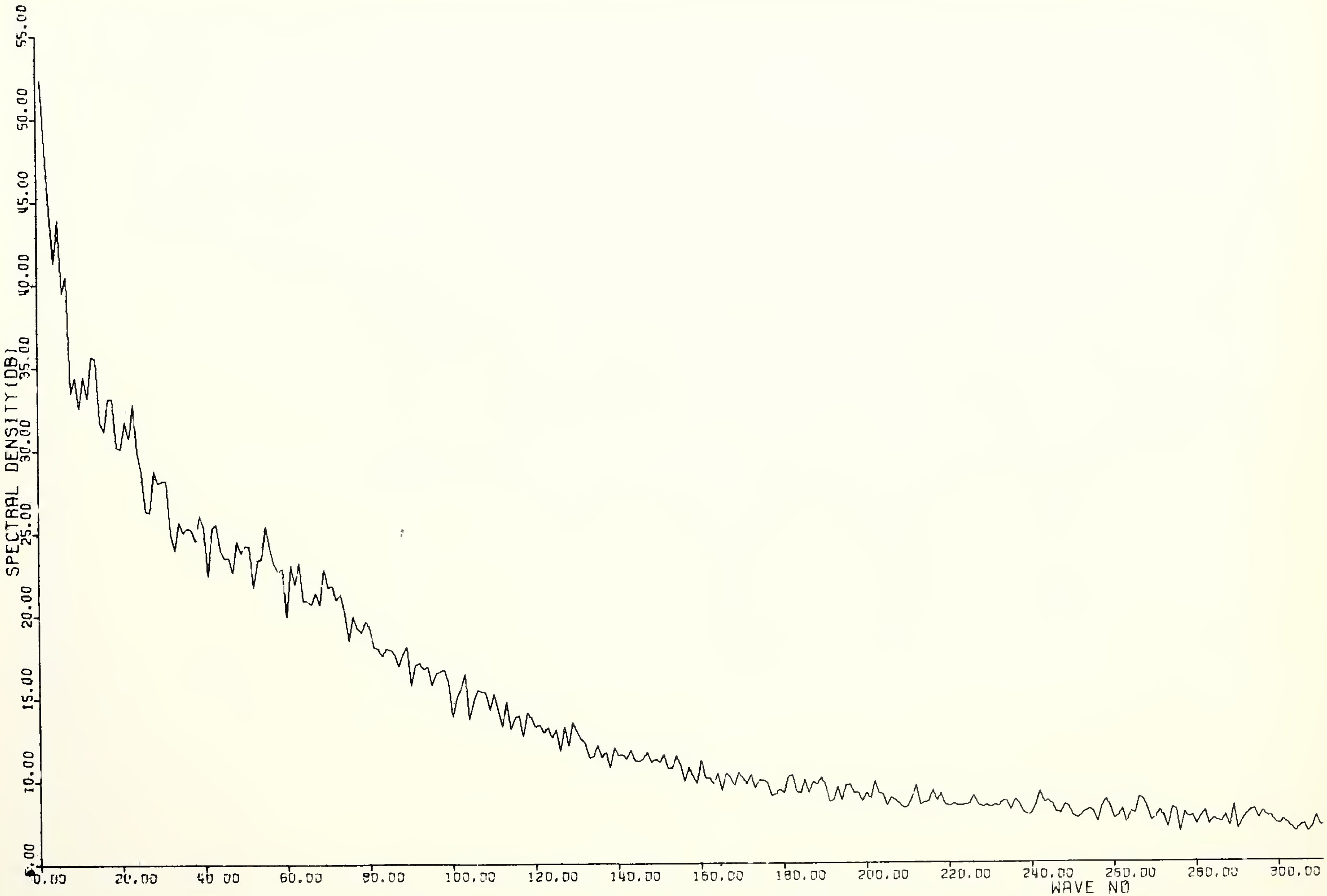

Figure 7-3.--Spectral response of VISSR visible channel for a stratocumulus scene

```
      1014.0
BIT ERROR RATE FOR LINES    1 TO  100 IS    2.9304600E-04
       994.0
BIT ERROR RATE FOR LINES  101 TO  200 IS    2.8726598E-04
      1172.0
BIT ERROR RATE FOR LINES  201 TO  300 IS    3.3870782E-04
      1207.0
BIT ERROR RATE FOR LINES  301 TO  400 IS    3.4882291E-04
      1307.0
BIT ERROR RATE FOR LINES  401 TO  500 IS    3.7772302E-04
      1240.0
BIT ERROR RATE FOR LINES  501 TO  600 IS    3.5835989E-04
      1349.0
BIT ERROR RATE FOR LINES  601 TO  700 IS    3.8986094E-04
      1339.0
BIT ERROR RATE FOR LINES  701 TO  800 IS    3.8697082E-04
      1398.0
BIT ERROR RATE FOR LINES  801 TO  900 IS    4.0402194E-04
      1514.0
BIT ERROR RATE FOR LINES  901 TO 1000 IS    4.3754582E-04
      1344.0
BIT ERROR RATE FOR LINES1001 TO 1100 IS    3.8841600E-04
      1541.0
BIT ERROR RATE FOR LINES1101 TO 1200 IS    4.4534891E-04
      1501.0
BIT ERROR RATE FOR LINES1201 TO 1300 IS    4.3378887E-04
      1504.0
BIT ERROR RATE FOR LINES1301 TO 1400 IS    4.3465593E-04
      1564.0
BIT ERROR RATE FOR LINES1401 TO 1500 IS    4.5199599E-04
      1754.0
BIT ERROR RATE FOR LINES1501 TO 1600 IS    5.0690584E-04
      1626.0
BIT ERROR RATE FOR LINES1601 TO 1700 IS    4.6991394E-04
```

Figure 7-4.--Diagnostic bit-error-rate printout. The number above the word "error" represents the number of word errors in each 100-line sector. Extreme right column shows bit errors per 10,000 samples (i.e., times 10^{-4}).

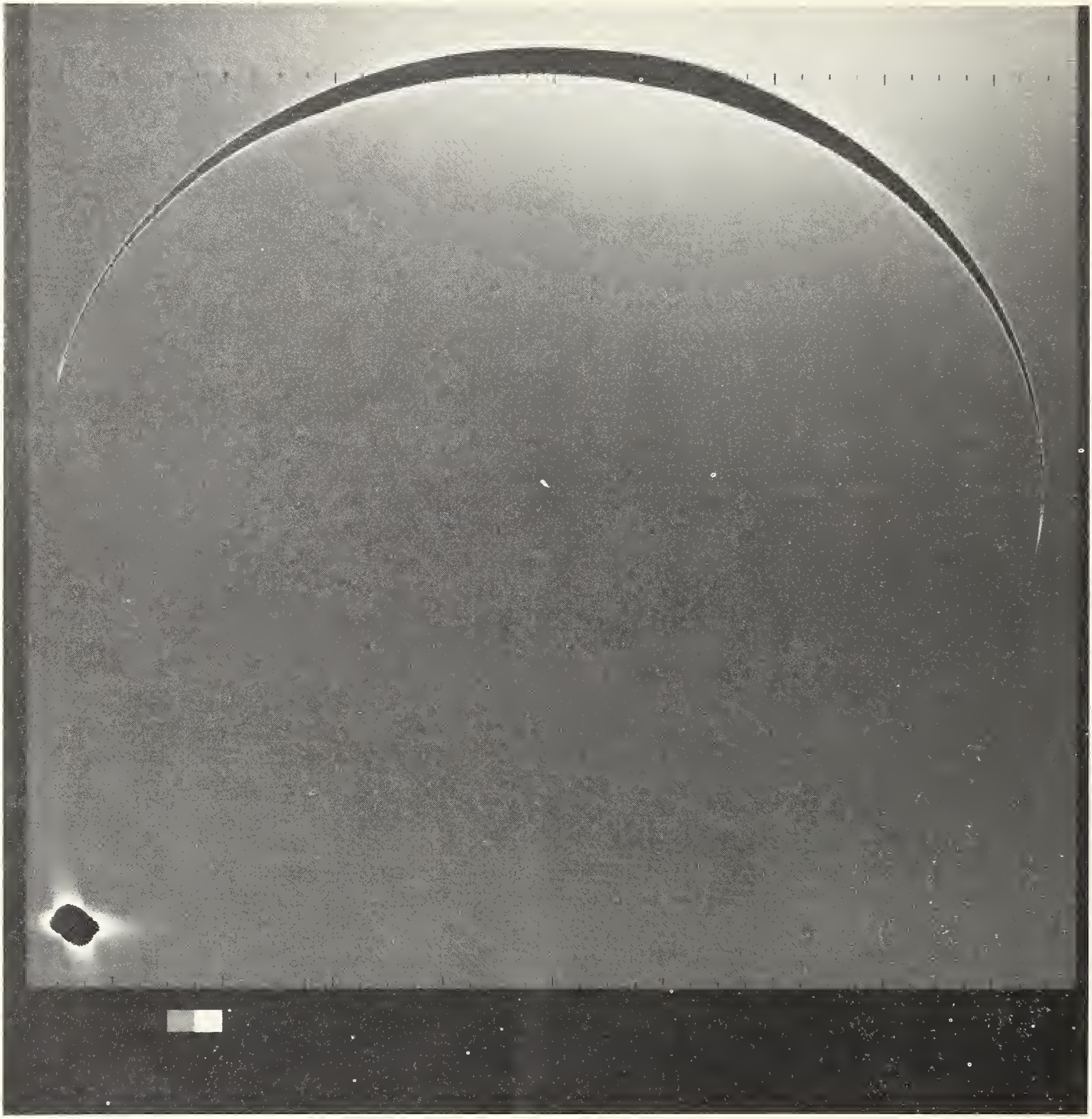

Figure 7-5.--Enhanced 4 x 4 visual image, all channels averaged, with solar image in lower left corner. The display gray scale is fully utilized by the lowest albedo data values. The type of optical dispersion from the prism (solar-calibration) is shown. Optical scattering of the sun shield is evidenced in the upper portion of the figure.

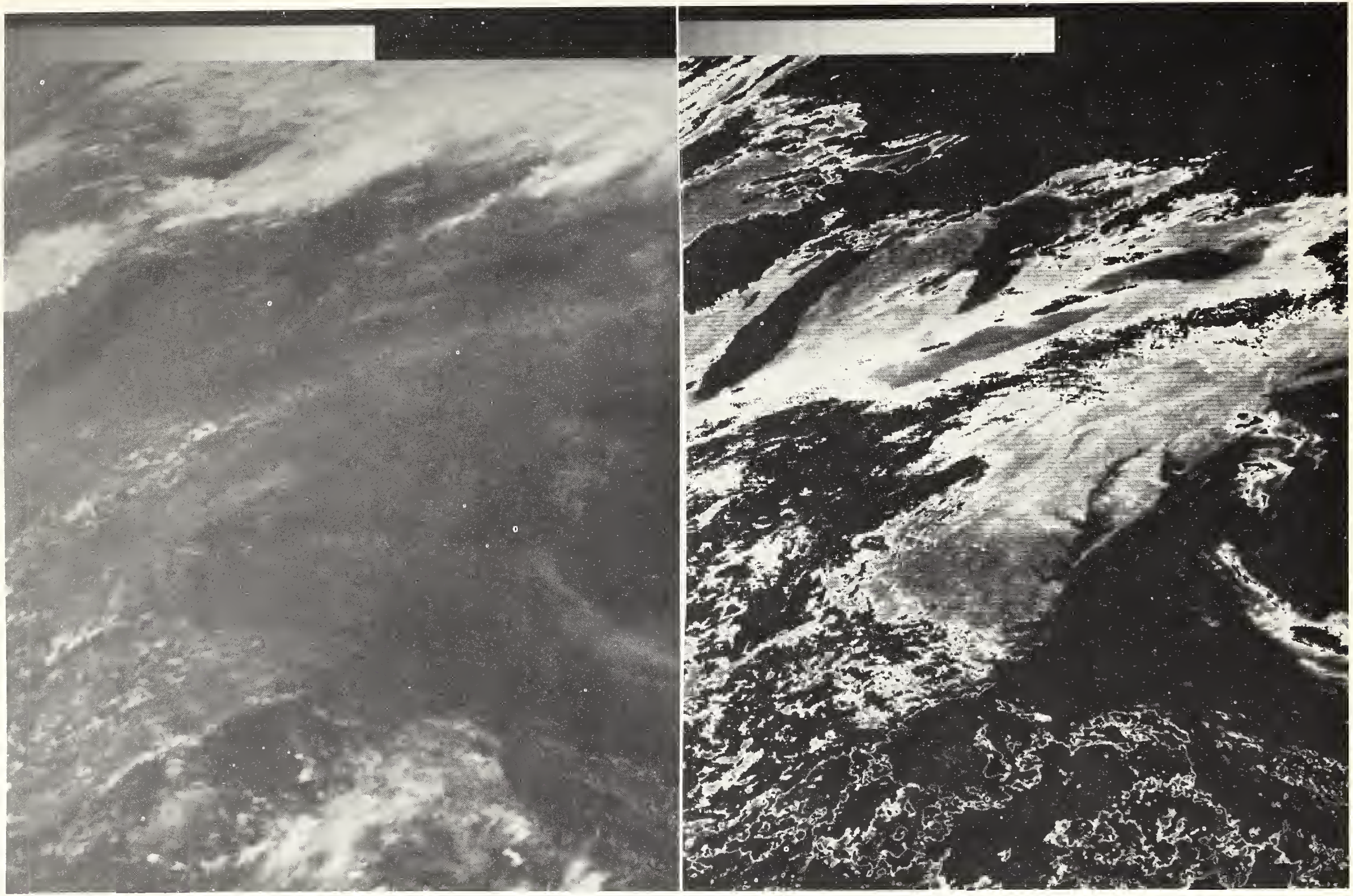

Figure 7-6.--Visible channel sector with normal display lookup table (left) and with enhancement (right)

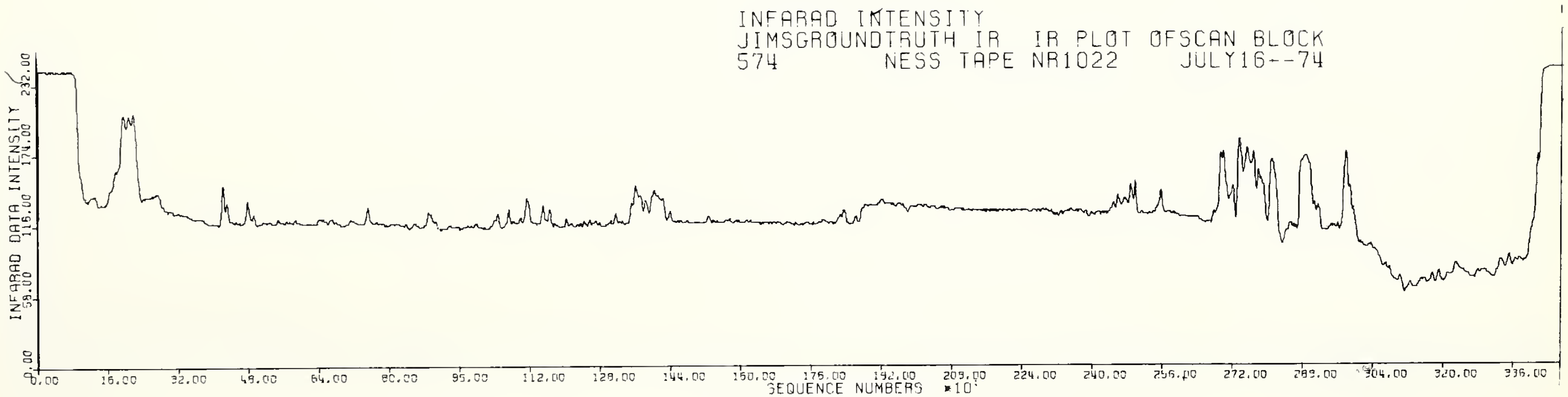

Figure 7-7.--IR scan profile produced by CALCOMP drum plotter

8

VISSR DATA CALIBRATION

B. Bauer and J. Lienesch

INSTRUMENT DESCRIPTION

The Visible and Infrared Spin Scan Radiometer (VISSR) provides measurements of the Earth in the 0.55- to 0.75-μm wavelength band during daylight and measurements of the emitted Earth radiance in the 10.5- to 12.5-μm wavelength band day and night. VISSR pictures of the global disk from synchronous orbits are generated by the progressive stepping of a scan mirror and the rotation of the spacecraft. During each spacecraft rotation the visible and thermal channel fields of view sweep across the Earth disk from west to east. The scan mirror moves one step per spacecraft rotation, thus providing a north-to-south progression of the fields of view. Approximately 18 minutes are required to scan the Earth from northern to southern Polar regions.

Eight photomultiplier tubes detect the reflected visible radiation from the Earth's surface and clouds. These eight sensors have fields of view of approximately 1 km. The fields of view are arranged in a north-south array, thus providing eight separate signals as the Earth is scanned from west to east on each spacecraft rotation. Four independent gain levels may be commanded for each visible sensor to correct for degration in signal level.

The two thermal channels are mounted in a dewar package incorporated in a radiation cooler. They operate at a thermostatically controlled temperature of approximately 95K. The two detectors each view an area of approximately 9 km. Normally only the data provided by one channel are used in operation; the second channel provides redundancy. A more complete description of the VISSR may be found in the Santa Barbara Research Center's VISSR Design Review Report.

PREFLIGHT CALIBRATION

Calibration of the visible and thermal detectors was accomplished during thermal-vacuum testing of the completed VISSR instrument. A collimator was constructed which filled the full aperture of the VISSR and could provide the visible and thermal spectral radiances required for radiometric calibration. The voltage output from the visible sensors was measured for eight levels of the Earth albedo ranging from 15 to 99 percent.

Similarly, the thermal detectors were exposed to a target whose temperature could be varied from 180K to 315K. All tests were repeated at five different temperatures of the thermal-vacuum chamber ranging from 0°C to 35°C.

The response of the two thermal detectors was also obtained when the inflight calibration shutter was commanded into the optical path of the detectors. This shutter, which obscures the optical path for one scan line at the beginning of each picture, is monitored by two thermistors. Thermal channel response to a target of known temperature is thereby obtained.

In addition, the calibrator was constructed to test the modulation transfer function (MTF) of all detectors. These tests were designed to verify the instrument's ability to sample adequately the rapidly changing energy levels during each 30-millisecond Earth scan. This test also was performed at five different instrument temperature levels.

A more detailed description of the preflight testing is contained in Santa Barbara Research Center Document No. 19060 (Abbott 1974).

GROUND TRUTH COMPARISONS

In any measurement system there is always considerable interest in the accuracy attributed to the measurements. Radiometric accuracy is of particular concern for the thermal channels where the data are used operationally in quantitative form. Comparison of the thermal measurements with other sources is difficult because of different conditions associated with the separate measurements. Sea-surface temperatures have been the main source of ground truth comparison for the VISSR. Unfortunately, the energy emanating from the sea surface is attenuated by the Earth's atmosphere. The VISSR measurement will necessarily appear to be too cold unless proper corrections are applied to account for the atmospheric effects.

Initial comparisons of the VISSR thermal measurements with sea-surface temperatures showed that the VISSR was measuring about 3K too cold even after correcting for atmospheric effects. At the time of these comparisons, the VISSR instrument was being subjected to large temperature gradients within the scanner. As these gradients decreased during the course of the year, the calibration obtained from the inflight calibration shutter provided data which resulted in better agreement with sea-surface temperatures. Typical differences between VISSR measurements and ground truth values are 3 to 5K, which represent the amount of attenuation by the atmosphere in the standard atmospheres observed by the VISSR.

IN-ORBIT CALIBRATION DATA SOURCES

The purpose of VISSR calibration is to provide a method of insuring accurate data independent of changes in scene and sensor environment.

The VISSR has two in-orbit calibration procedures for both the visual and thermal (or IR) channels. One calibration procedure utilizes a 0- to 5-volt staircase response inserted in both the visual and thermal channel signal paths. The other calibration procedure utilizes two targets for both the visual and thermal sensors. The visual channel targets provide space and solar observations. The sun, as viewed through an energy reducing prism, provides an equivalent Earth albedo response of approximately 50 percent. Space provides a 0 percent albedo response. The voltage response of the visual channel is linear with incident energy.

The thermal channel targets are space and the calibration shutter. The space view provides a near zero response while the shutter view provides the response to a target of near 300K. The range of temperature responsivity of the thermal detectors is approximately 100 to 330K.

GROUND-BASED CALIBRATION PROCEDURES

The VISSR calibration programs (VSRXXX)[1] evaluate the documentation, electronic staircase, space, shutter, and solar observations for both the visual and thermal channels. Telemetry data are obtained from a separate source. The final products of the calibration software are counts-to-temperature for the IR thermal tables and counts-to-albedo for the visual tables. For the thermal channels, response ranges from 0 to 255 counts for scenes of 160K to 330K. For the visible channels, response ranges from 0 to 63 counts for 0 to 100 percent albedo.

There are two sources of sensor data for the calibration programs. One source is the VISSR Ingest Computer (GT&E TEMPO II); the other is the UNIVAC Series 6000/6135. Either can provide the VSR programs with the shutter, staircase, and space observation on the fourth, fifth, and sixth scan lines, respectively. The solar image location expressed in relative Earth image coordinates is computed by VSR511. The Julian day and longitudinal subpoint of the spacecraft are required by this program. The lateral position is expressed in terms of 4 x 2 IR sample locations (0 to 3822), and the N-S location is provided in terms of scan line number (1 to 1821).

The thermal channel staircase is evaluated for deviations from linearity. If nonlinearity is noted in one of the thermal detectors, it is an indication that more than two points are needed to determine the proper digital count response-to-scene radiation. The thermal channel solar image and sea-surface temperatures have been proposed as alternate targets to calibrate the thermal channels in the event of limited nonlinearity. The targets mentioned above have not been utilized for calibration purposes at this writing.

The Visual channel staircase approximates a square root function, i.e.,

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[1] VSRXXX is the mnemonic name for all calibration programs ($000 \le XXX \le 999$).

$$C \simeq 28.1\ (V)^{\frac{1}{2}} \tag{1}$$

where C = digital counts

and V = volts

Equation (1) represents the nonlinear curve that converts volts to counts. Solving for V,

$$V \simeq (28.1)^{-1}C^2\ . \tag{2}$$

The computed volts from eq (2) are used to compute the albedo, A, where

$$A(\%) = 0.2V \times 100 \tag{3}$$

The underlying assumption in eq (3) is that the solar energy through the calibration prism is equivalent to a 50-percent albedo source. The albedo-to-volts relationship is linear and permits calibration of the visual channels using two points. The space and solar observations for the channel which has the largest dynamic range are used to create a normalization table for all channels. A second approach uses linear regression which chooses the "best" reference channel to which the other channels are normalized; the regression is performed to compute albedo as a function of volts.

At the present time, a normalization of the visual channels has been achieved so that no stripping will occur because of biased sensor responsivities. We have attempted to utilize the Moon and Jupiter for calibration targets. However, because of their low albedo levels, generally below 1.0 volt, we have not been able to utilize extraterrestrial targets to ascertain visual channel calibration.

The thermal channel evaluation begins with a check of staircase linearity and proceeds to a radiometric calibration utilizing space and shutter observations. The space observation of the thermal channels is evaluated by VSR380. This program uses Student's T-test to compare the current and previously observed response from space. The current space observation is passed to the VSR430 program.

VSR430 computes the average shutter observation, S_a, which is compared to the previous shutter observation, S_p. An associated T-value is obtained for the 95% confidence level. VSR430 computes the average scanner temperature, T_A, to ascertain whether the optical path is isothermal with the shutter. T_A is the average temperature of the primary and secondary mirror and primary and redundant shaft encoders. The shutter temperature, T_S, is computed from the average of two shutter thermistors. The effective shutter temperature, T_E, is then expressed as,

$$T_E = T_S + e_A (T_S - T_A) \tag{4}$$

where e_A, which is equal to 0.325, is a coefficient derived from the emissivities of the scan mirrors, primary and secondary mirrors, and the secondary mirror obscuration. If the shutter is isothermal with the scanner, then

$$(T_S - T_A) = 0, \text{ or } T_E = T_S \tag{5}$$

If the scanner is not isothermal to the shutter, then the shutter temperature, T_S, is corrected for energy contributions from the scanner by eq (4). The T_E of eq (4) is then used in eq (6) below to compute the energy $R(T_E)$ of the shutter:

$$R(T_E) = \frac{\int_{10.5}^{12.8} B(\lambda,T_E)\phi(\lambda)d\lambda}{\int_{10.5}^{12.8} \phi(\lambda)d\lambda} \tag{6}$$

where B (λ,T) is the Planck function, λ is wavelength in micrometers, and ϕ (λ) is the spectral response of the detectors. The gain, G_a, of the detector is then computed as follows:

$$G_a = (C_s - C_z)/E \times R(T_E) \tag{7}$$

where E = effective emissivity of the shutter derived from pre-flight data (E = 0.955, for SMS1),

C_z = space response (signal level while viewing space), and

C_s = shutter response (signal level while viewing calibration shutter).

G_a is compared to the previously computed gain, G_p. If G_a is significantly different from G_p, we then compute a new calibration curve.

The new calibration curve which relates scene temperature to counts, C, is produced in VSR710. VSR 710 utilizes the gain computed in eq (7) and the space signal level, C_z, to compute a calibrated counts-to-temperature relationship. The gain, G_p, is equal to the slope, M, for the counts to energy curve which is linear. Therefore, the energy, R, is expressed as follows:

$$R = M \times C + b, \text{ for } C = (0,...,255) \quad (8)$$

where $b = -M \times C_z$.

The R computed in eq (8) is passed to the inverse Planck function to compute temperature, T_i.

$$T_i = C_2/\lambda \ln [(C_1/R \times \lambda^5) + 1] \quad (9)$$

where $\lambda = 11.4\ \mu m$,

$C_1 = 1.1909 \times 10^4\ W\ cm^{-2}\ sr^{-1}\ \mu m^4$, and

$C_2 = 1.43879 \times 10^4\ \mu m\ K$.

The T_i in (9) are then processed through the NOAA standard curves (10a and 10b):

$$C_i' = 2.0 \times T_i - 406 \qquad 242 \leq T_i \leq 330K \quad (10a)$$

$$C_i' = T_i - 164 \qquad 163 \leq T_i \leq 242K \quad (10b)$$

The C_i' produced in eq (10) are passed through (11):

$$C_i'' = 254 - C_i' \quad (11)$$

This curve inverts counts so that cold objects (high clouds) appear white in photographs, and warm objects (sea surface) appear dark in accordance with visually observed atmospheric phenomena.

ECLIPSE ANOMALIES AND OTHER CALIBRATION CHANGES

It has been observed that the radiometric calibration of the thermal channels vary during the eclipse period as the scanner temperatures change. An evaluation of one day's eclipse shows errors greater than 2K up to 2 hours after VISSR turn-on following eclipse. Temperature errors appear to decrease to less than 1K after 6 hours.

Users should exercise caution in utilizing the infrared data obtained during the first few hours after VISSR turn-on. A satisfactory method of compensating for changing thermal detector sensitivity during the eclipse periods has not been developed at this writing. Temporal changes in the sensitivities of the visible channels as a result of the eclipse event have not been detected.

After the launch of SMS-1, it was found that the technique for calibrating the VISSR from the in-flight calibration source was not adequate. This was discovered by comparison with ground truth measurements and by the fact that the sensitivity of the detectors, as computed from the calibration model, was changing as the instrument temperatures changed. Detailed analyses, performed in connection with the development of the VISSR Atmospheric Sounder (VAS), substantiate the fact that the initial calibration model was inadequate.

To calibrate the VISSR measurements under these circumstances requires the development of empirical techniques which can be verified from the in-flight results. The analysis of the VAS system, which is similar to the VISSR, indicates the need to monitor the temperatures of a number of optical elements. Because some of these elements are not monitored in the VISSR, an attempt is being made to develop a calibration algorithm based upon regressions on the available scanner temperatures. Verification of newly developed approaches will continue as in-flight calibration data accumulate.

IN-FLIGHT CALIBRATION LIMITATIONS

The most severe limitation of the in-flight calibration of the thermal channels has been associated with the changing thermal gradients within the sensor-scanner unit. Ground truth observations have been used to ascertain corrections to the in-flight calibrations. The adequacy of these corrections needs to be verified for a full annual cycle. These problems arise because the thermal calibration shutter does not provide a measure of total instrument response. A precision attenuating circuit is provided for measuring total instrument response during equinox periods when the VISSR views the sun. Unfortunately, instability in this signal has thus far prevented use of this method for determining total response.

The Visual Channels have been normalized once, on October 30, 1974. A failure of PMT #7 occurred on July 10, 1974. At that time the signal from Visual Channel No. 6 was inserted into the Visual Channel #7 data link for retransmission to the SFSS. The emphasis for the visible sensors has been directed to the elimination of striping rather than maintaining radiometric calibration.

9

VISSR DISPLAY PRODUCTS FROM THE CENTRAL COMPUTER OPERATION

C. L. Bristor

INTRODUCTION

A central VISSR sectorizer facility supplies images directly to major field service centers via conditioned land lines (Hussey 1974). Apart from that activity, the facility supplies a variety of computer-processed image products to various users of satellite data. In the first instance, the direct service provides for prompt delivery of essentially raw image products. In the latter case, the raw image data are exposed to a more complicated treatment process to create display products with enhanced utility. Certain desirable image data manipulations may be prohibitive if done by human analysts while equivalent treatment by computer might be practical. In each case one must weigh the increased complexity and resource commitment (question of reliability and possible delivery delays), against the improved utility of the derived product.

This report describes several derived image products. Some are now operational, others are in operational test, and still others are in more preliminary stages of consideration.

The display media of principal concern for computer-manipulated image products are the standard photofacsimile displays (Muirhead, Datalog, or similar recorders), standard weather facsimile network (FOFAX, NAFAX) displays, such as Alden electrolytic paper recorders, and weather facsimile images rebroadcast via geostationary satellites (WEFAX) and recorded on either photofacsimile or other facsimile recorders. In all cases, computer-generated digital image source signals are transformed to appropriate analog recorder signals within the Digital Muirhead Display/Facsimile Encoder Transmitter (DMD/FET) as mentioned in the initial paper of this memorandum.

UNMAPPED DISPLAYS AND OPTIONS

The implanting of earth locator gridding information is described earlier in this report. In a sense, such raw image displays are "derived" products, in that substantial computer support is required in the grid calculations, and other melding operations are required in the S/DB. Here, only those display aspects apart from the Satellite Field Service Division (SFSD) activities are discussed.

Figure 9-1 shows a pair of gridded images produced on a photofacsimile recorder. Each picture element is presented as a 6-bit byte (64 levels), and the image is recorded at 250 samples per inch on a 10-in film square. A similar FOFAX product is shown in figure 9-2, where 1710 picture elements are displayed on each line. The square mesh array on 18-in wide paper is recorded at 96 elements per inch. Smaller 800 x 800 element arrays are transmitted via WEFAX (fig. 9-3). Two such frames of imagery may be transmitted in each available 10-min time slot between the half hourly acquisitions of VISSR data.

Apart from options discussed earlier in the description of the gridding operation, there also exists considerable flexibility in equating raw picture element response values to display gray shades. This option to provide a variety of enhancements is done through a simple table lookup transformation. Examples are shown in figure 9-4.

The procedure by which coastlines, latitude-longitude lines, and other physiographic features are implanted in VISSR imagery also provides the means for other product options. For example, various contour charts (analyses and prognostic topographies) produced by numerical weather prediction operations can be implanted in similar fashion. A test example is shown in a following section of this memorandum. (See Bittner et al.)

Unfortunately each enhancement or other special treatment represents another resource commitment which must compete for computer time with alternative products (different picture time, sensor channel, area viewed, or spatial resolution). As described below, unmapped image products also must compete with other image products.

The schedules and content of the various image dissemination systems is periodically reviewed through meetings of a Product Review Working Group (PRWG), and the current image product mix is checked through appropriate transmission schedule documentation.

MAPPED IMAGE PRODUCTS

The Mercator-mapped VISSR image already shown earlier in this report represents the basic source for other related display products. Sectors of the map array on computer disk may easily be extracted and labeled to provide alternate products for FOFAX and WEFAX dissemination. Samples are shown in figure 9-5. As in figure 9-4, mapped imagery may also be enhanced. Figure 9-6 presents a variety of enhancements using multiple displays of an IR image sector mapped in polar stereographic form. Where more quantitative insight is required, limited outputs may be obtained as alphanumeric graphics. One such requirement involves the tracking of the west wall of the Gulf Stream off the southeastern United States; a computer printout for that application is available as a diagnostic tool.

In addition to the options mentioned in connection with unmapped images, there exists a considerable potential for more sophisticated image products that use mapped imagery as the basic data source. This is possible because deformational variations have been removed through the geometric normalization of the mapping process.

One current effort involves time-compositing mapped images. Earlier use of multi-day composites of mapped ITOS image data suggests the potential value of a similar production effort with VISSR data (McClain and Baker 1969, and Barrett 1974). One such application of 5- and 10-day minimum brightness composites indicated utility in monitoring snow conditions. It appears that VISSR data may provide a more valuable tool for tracking snow storage and snow melt situations since the compositing to eliminate cloud cover contamination may now be based on several images each day and so reduce the time span of each composite image production. One may speculate on the use of higher resolution (half mile) VISSR data in composites for limited drainage basins as a tool in the automation of snow storage measuring techniques recently developed using similar resolution VHRR data (Wiesnet 1974). Once a cloud-free composite image of a snow field is generated automatically, one must then precisely establish boundaries in agreement with a pre-established basin reference template. A cross correlation technique which juxtaposes landmark features could likely be used in this task. (See Novak et al., elsewhere in this report.) The planimetered measure of brightness contours (snow amount) as a function of time then provides trend information on snow accumulation or depletion. At present this remains a developmental task.

Another likely product is a two-image combination which may reveal short period (one to several hours) changes in singular features. If mapped images are reduced to the presence or absence of some wanted response (a designated temperature or brightness interval) at each picture element location, then each image is reduced to a simple event/non-event binary array. Earlier experiments with ATS picture combinations suggest a four-shades-of-gray combination which readily reveals event 1, event 2, both events, or neither event. Development of such a display tool could be used to measure translational movements of squall lines and shifts in the centers of convective development within them. In this instance, such trend indications would be most valuable if the cloud systems were so treated before the development of significant radar echoes. Again, this item is a contender for developmental resources.

Some thought has also been given to stereo displays as a means of revealing the 3-dimensional structure of clouds. Once the dual GOES system is fully operational, a substantial overlap region will be viewed by both spacecraft. (See fig. 1-9). To remove the differing deformations of the viewed cloud patterns, it is proposed that coincident images in mapped form be used for the 3-D viewing (Bristor and Pichel 1974). A limited feasibility study is being carried out.

Two-channel display combinations present other product possibilities. If certain combinations of coincident IR and visible channel responses are of interest, then these may be displayed in terms of assigned gray scale values. For example, this method might be used to produce a thermal convection analysis in which deep convective activity (represented by some bright/cold limits) is displayed at one gray level and thermally stable zones (bright/warm for low stratus) are displayed differently. Limited experiments have been conducted with such dual channel displays.

Other types of derived displays will, no doubt, occur to the reader. In most cases there is an advantage in dealing with mapped image data, but in some applications the precision of the mapping is critically important. Hopefully, navigational inputs will satisfy the required precision, but certain uses (such as in squall line displacement measurement) may still depend on landmark matching as the final tuning step.

The papers following this one deal with manually derived products or automated quantitative extractions that involve displays. Since such displays tend to be diagnostic in nature, or are used primarily as tools in the information extraction process, they are included in the appropriate sections as incidental background.

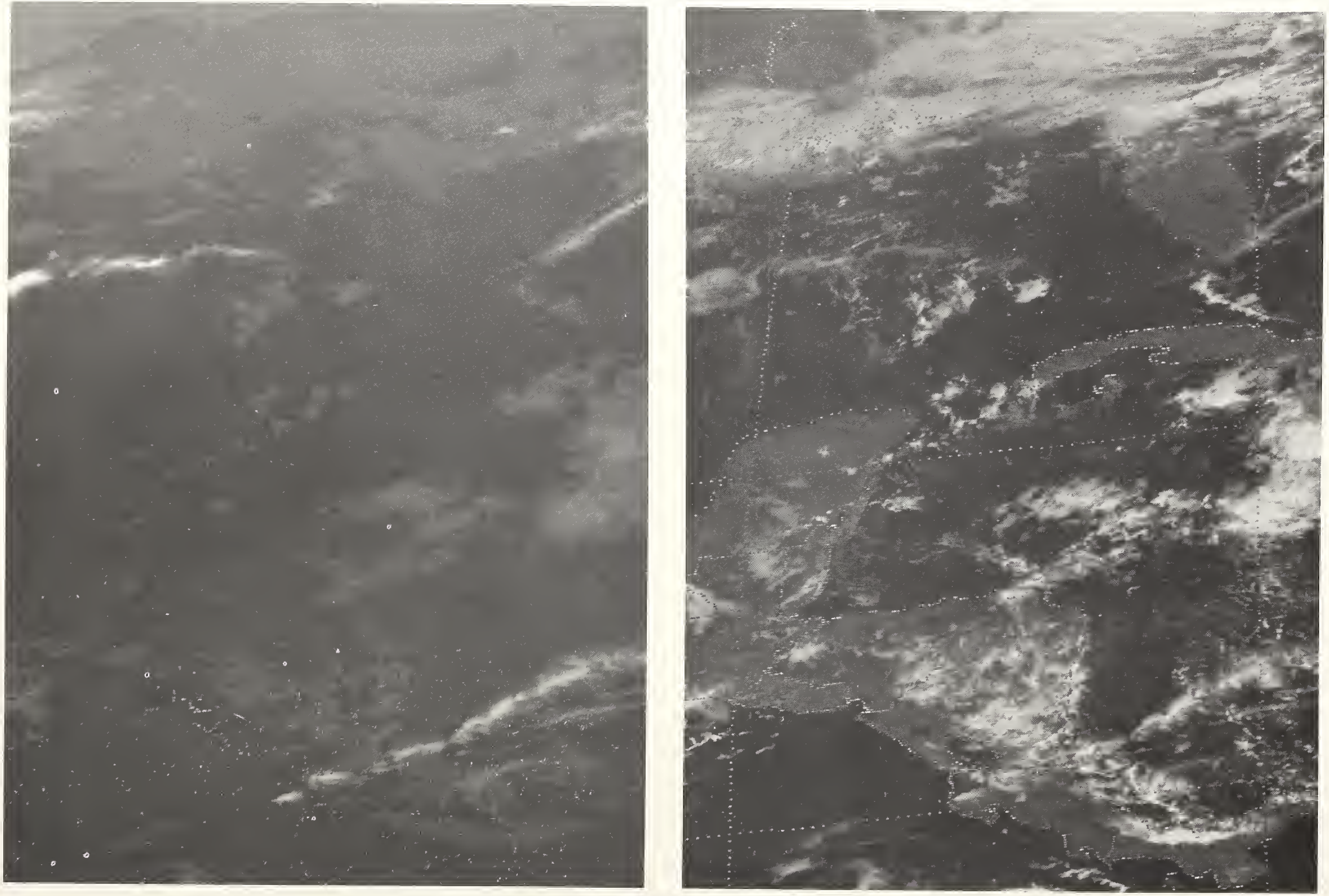

Figure 9-1.--Gridded visible channel 2-km sector (right) with companion IR view (left)

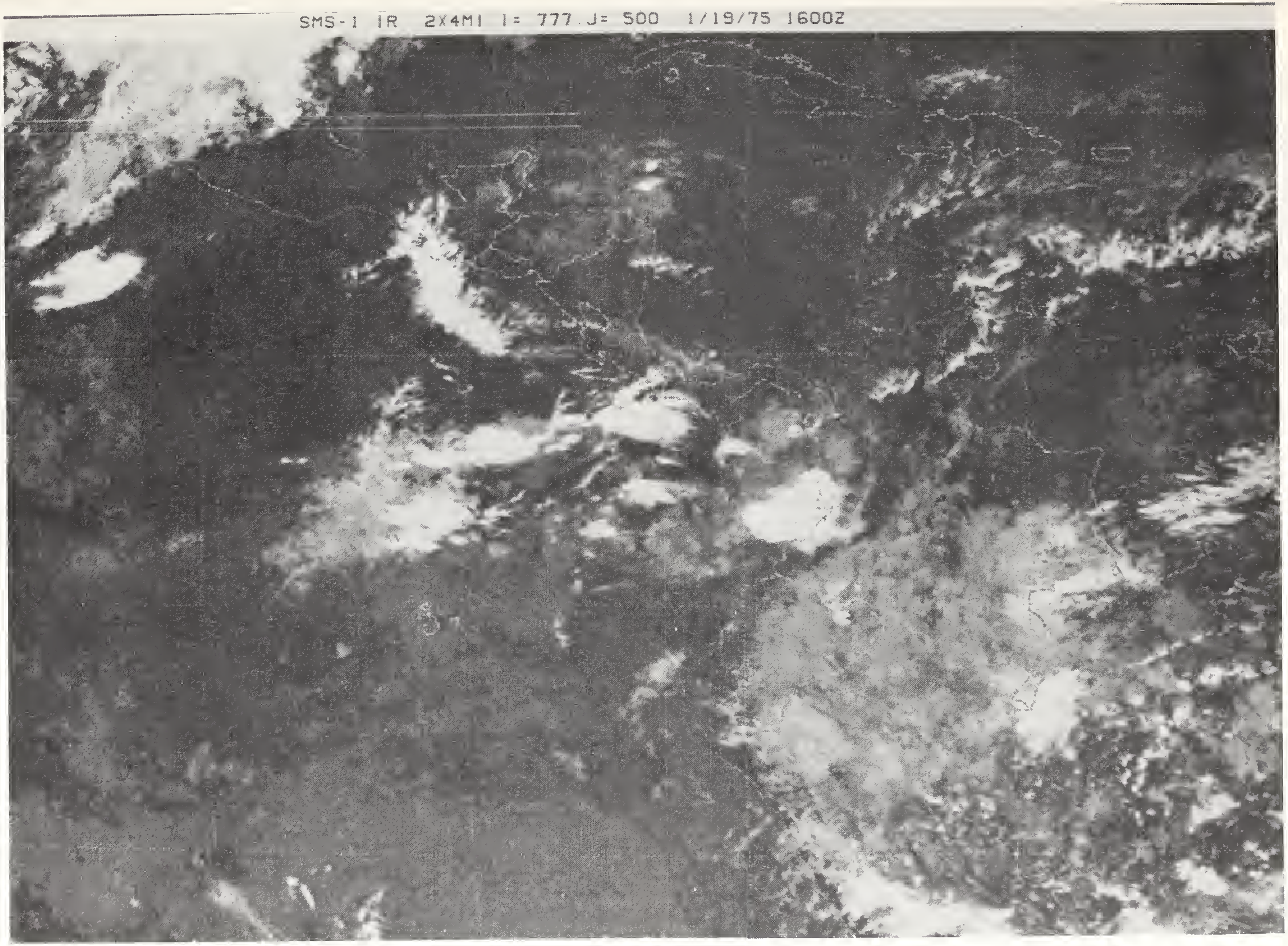

Figure 9-2.--Facsimile image with grid. At 130 lines per minute, such images may be fitted to available transmission time slots.

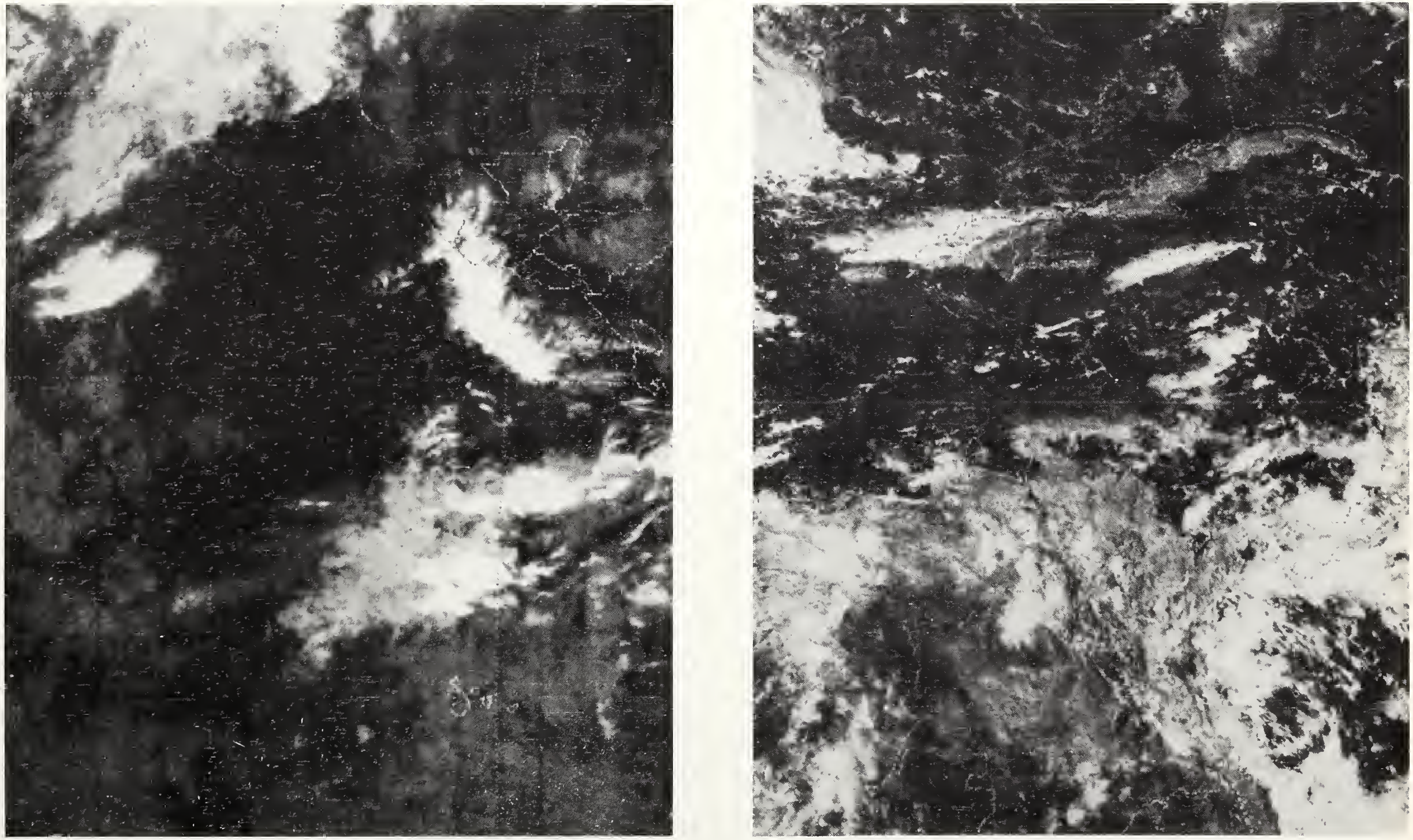

Figure 9-3.--WEFAX gridded VISSR images. Although a transmission may be truncated, each "frame" consists of an 800 x 800 element array to maintain compatibility with original APT display specifications. Frames shown are an IR frame (left) and a visible channel frame (right).

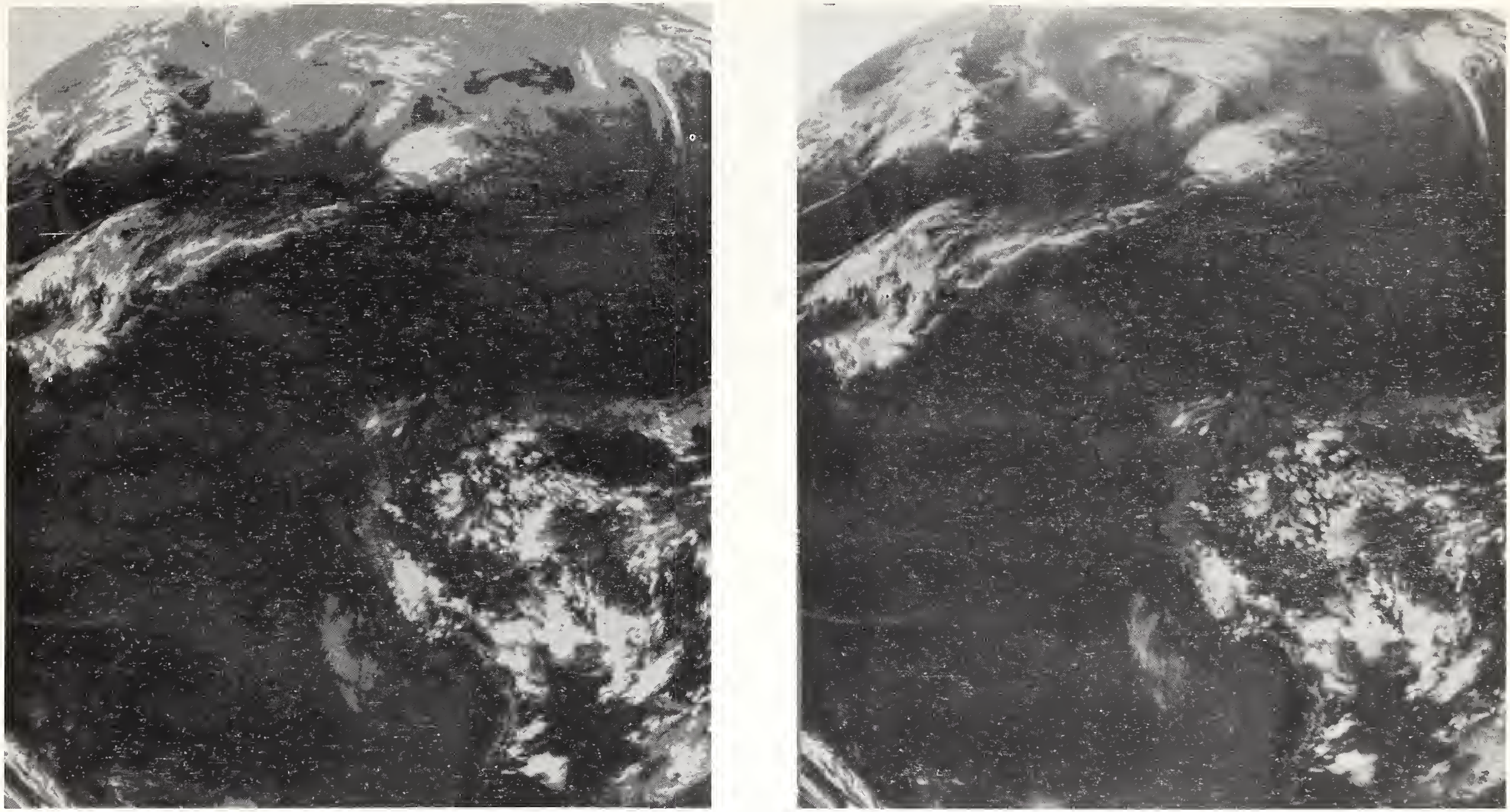

Figure 9-4.--(Left) enhanced VISSR IR image with only four gray shades shows potential for display of surface, low, middle, and high cloud regimes. The equivalent full-range display is shown at right.

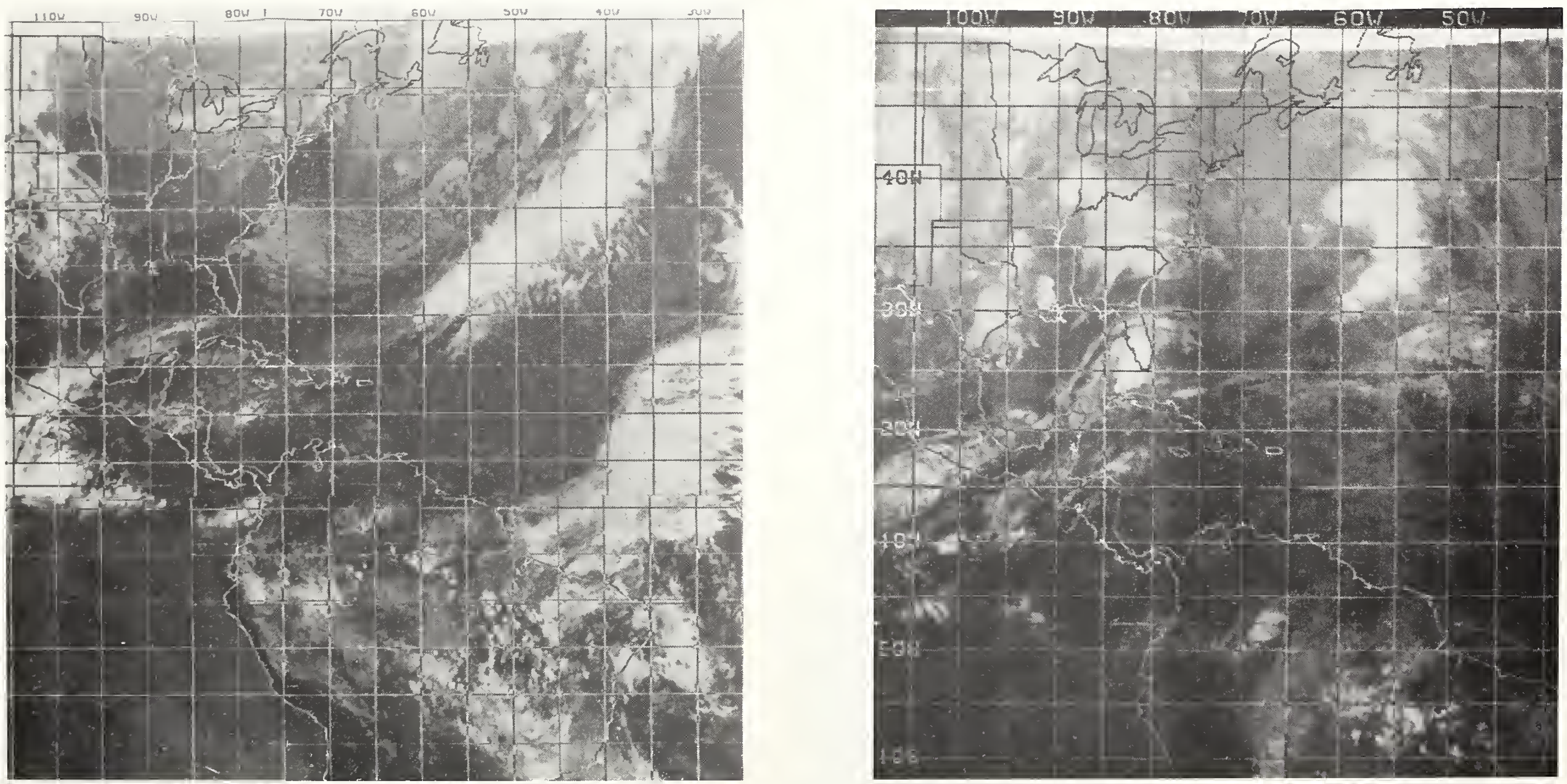

Figure 9-5.--Mercator mapped images transmitted by facsimile and displayed on electrolytic paper recorder. A sample intended for land line distribution is shown at left, and an 800 x 800 sample WEFAX array is shown at right.

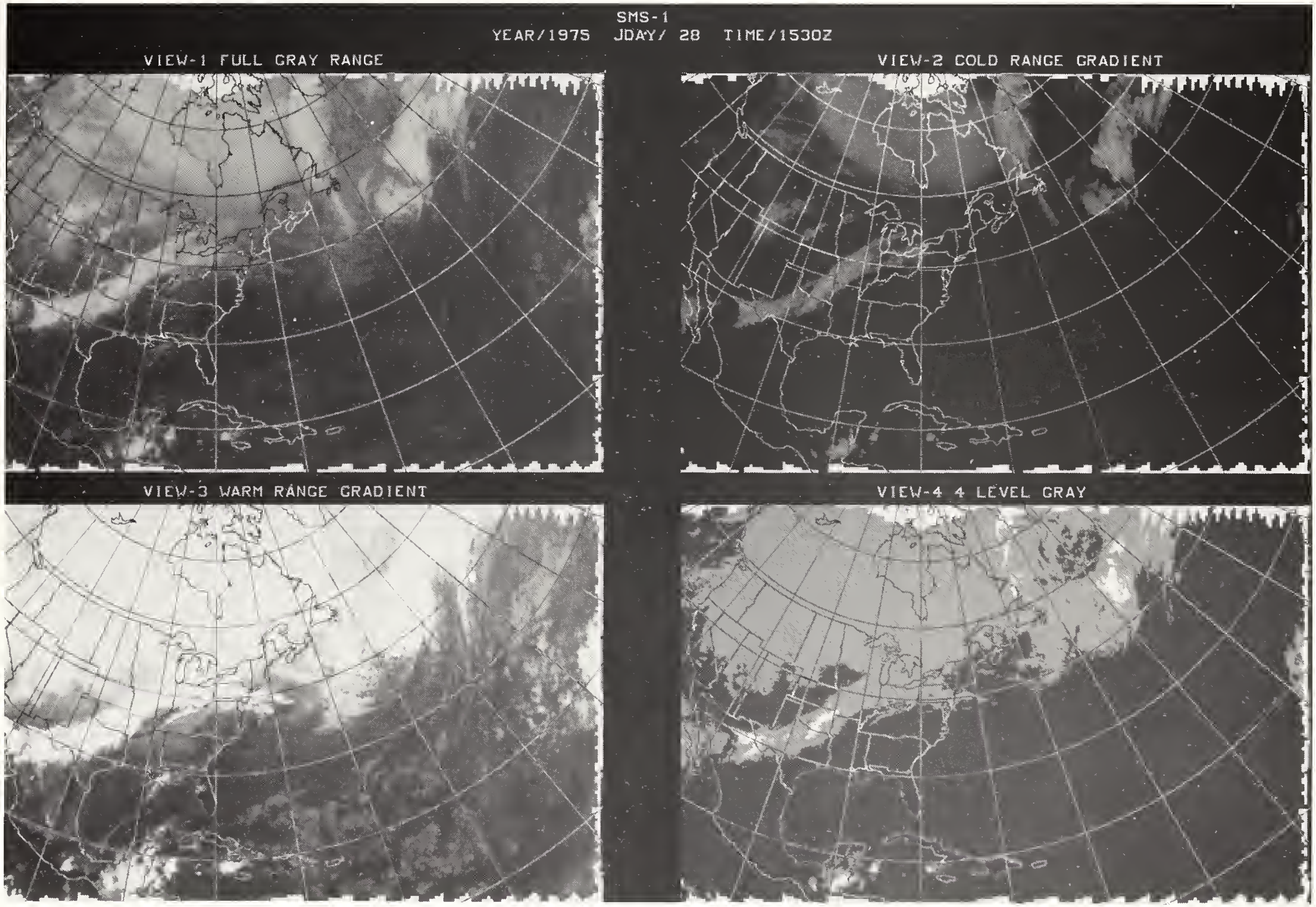

Figure 9-6.--Polar mapped IR sector displayed in full gray range and in enhanced versions

10

VISSR PICTURE ANIMATION AND MOVIE LOOPS

W. Plew and A. Thumim*

INTRODUCTION

Routine half hourly acquisition of full Earth disk imagery first became possible when NASA's ATS-1 satellite became operational late in 1966. Those interested in the changing cloud patterns were soon devising means to combine individual pictures into animated sequences.

In the late 1960s, several alternative designs for the display of geostationary satellite Earth image sequences were explored. One system, devised by Dr. T. T. Fujita of the University of Chicago, involved illumination of 10-cm photo prints with a stroboscopic light. Images were carefully registered and monitored on a flat rotating disk to produce animation (Fujita et al. 1968). Another team, under Professor V. E. Suomi of the University of Wisconsin, experimented with a half-silvered mirror to juxtapose an image pair. Animation was achieved with alternating stroboscopic "blink" illumination (Schwalenberg 1969). Within NESS, L. F. Hubert devised a system by which registered sequences of negatives were re-recorded on video disk using a TV camera. Animation was then achieved by displaying the sequence on a CRT. (See Hubert et al. 1971, and Serebreny et al. 1970.) V. J. Oliver and other groups were also experimenting with movie loops made by kinescope rephotography of registered negative sequences.

Much insight was gained during this experimental phase by noting the strengths and weaknesses of the various competing systems. The loop movie emerged as the favored operational approach, since it seemed to offer some advantage in its flexibility. The number of negatives used in each loop was optional as was the sequencing and exposure cycling. Once registered, the negative sets could easily be manipulated to produce loop families with exposures of different enhancement, spatial resolutions, and fields of view. Anyone could use the loop with commonly available projectors. This paper reviews early equipment developments in the evolving ATS loop operation, and describes in some detail the current, more sophisticated loop production facility for GOES operations.

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ATS OPERATIONS

Early in 1969, the Hughes Corporation demonstrated a loop movie production capability using a 16-mm Bolex camera and preregistered 25-cm negatives which were photo recorded on a modified Muirhead photofacsimile display device. By April, the NESS Visual Products Support Branch had installed a mounting column for the camera together with a "compound" negative mounting stage which permitted lateral displacements of the negatives orthogonal to the overhead camera. With a powered "zoom" arrangement that required manual focus, a facility was devised for producing loops ranging from full Earth disk views down to 600-km sectors.

By June of 1969, wind estimates from loop movie cloud displacement measurements were being made operationally. Weaknesses soon became evident as the operation continued, so a number of improvements were made.

During the early 1970s, the solar wind effect caused the orbits of both ATS-1 and ATS-3 to become more inclined. In each case, the north-south 12-hr satellite motion eventually exceeded 1,000 km. The resulting changes in distortion (foreshortening) between frames became extreme. Because all animation schemes require precise frame-to-frame registration, this became a primary problem. Prepunched Mylar strips taped to the negatives were entirely satisfactory for pin registry prior to kinescope recording, but a compromise solution to the alinement problem was needed to assure procedural uniformity and operator-to-operator production stability. As a partial solution, rules were developed that called for the selection and use of specific landmarks for the various loops produced daily.

A mechanical analog device which held and shifted each source negative was another stabilizing development. This device, designed by Professor Fujita, involves a wheel-cam-lever arrangement that simulates the satellite's cyclic change in viewing perspective. Once locked at a selectable picture start time, the device provided a displacement shift position for each successive negative so that selected landmark features were held in fixed position throughout film loop production.

Apart from geometrical registration problems, early loops exhibited a cyclic exposure variation because the negatives were uncorrected for variation in scene illumination. A through-the-lens electronic exposure control device was incorporated with the camera system to compensate for such variations.

As the operation expanded, other system problems arose. Camera wear and component fatigue began to cause frequent breakdowns and equipment outages. This problem, and the growing penalty of time lost by manual exposure and focus adjustments, prompted procurement of equipment better suited to operational production. As a result, NESS purchased an Oxberry 16-mm film maker, a camera system designed to produce motion pictures from still scene sequences. The camera-holding column has zoom capability and an automatic focus-following feature. The heavy and rigid compound stand, mounted directly beneath the camera, may be shifted in both X and Y directions by lead screws. Another valuable feature permits projection of the camera aperture on the source negative so the operator can see and make fine adjustment to the actual area being photographed. These features greatly facilitated loop production.

Subsequently, the NESS Satellite Experimental Laboratory and Visual Products Support Branch developed a new under-the-negative illumination system. Early efforts involved a through-the-lens photo-sensing cell which controlled power to an incandescent lamp array below the negative. However, with reduced power, lamp output shifted toward yellow in the visible spectrum; this disturbed the system because the film was most sensitive in the blue-green region. Tests with gas-filled lamps exhibited an objectionable flicker as power was reduced. The final solution retained the cooler operating gas-filled lamps but used a lens-diaphragm controlling servo system actuated by the through-the-lens photo cell instead of lamp power variation.

During this period operators developed effective production procedures. The valuable insight gained was helpful in developing further improvements for the new facility needed for GOES operations.

THE GOES LOOP PRODUCTION FACILITY

Although the system described above worked well with ATS spin-scan data, loop production using VISSR data from SMS-1 in the new dual spacecraft operation required review of human resources and system capabilities. With 1-km visible channel resolution and plans for more stringent control of satellite position, there was need to maximize geometric precision. The dual system, with both night and day imaging capability, was also generating a much larger amount of data from which loops would be required. Experience with ATS had broadened user interest so we were faced with a great increase in user demands. Including winds loops, the new operational products are flow loops of various time durations using both visible and IR channel data at different spatial resolutions, over different geographic regions, and at different gray-scale enhancements. The needs of R&D programs were also increasing: This workload increase prompted careful scrutiny of the ATS system with a view toward increasing automation and labor saving changes. The present computer controlled system evolved from these design considerations, and the functional attributes listed below were considered both desirable and vital. These considerations require the system to be capable of:

1. Intermixing different sets of input negatives, with different spatial resolutions and exposure characteristics;

2. Creating many kinds of loops (e.g., back-and-forth sequences, first and last image stop loops), with different sequence start points and numbers of source negatives on an intermingled basis;

3. Extreme accuracy of negative positioning, repeatability, and precise camera alinement;

4. Reliable, continuous operation with optimal performance design margins;

5. Automated operation with minimum human intervention and supervision; and

6. Operation at effective speeds, so users can have the desired loop within minutes after submission of the final source negative.

To meet these capabilities, NESS procured several Oxberry computer controlled stands. The basic system is rugged and has comfortable design margins for heavy operational use. There are eight positioning motors for its operating functions, all of which are controlled through a PDP-8 minicomputer.

One of the significant computer controlled functions is automatic exposure compensation. To compensate for variations in source negative scene density, the system senses the amount of light that would reach the film and converts this value into a number by which the computer calculates the proper camera speed. Using this method, compensation is achieved by changing the camera speed without varying the lens f-stop. If the maximum camera speed is exceeded, or if the scene is too dark, exposure is inhibited and the computer types out a message indicating the situation.

Another important feature is the alphanumeric character generator used for automatic insertion of labelling and documentation information on the film loops. This is done with a miniature high-resolution CRT in the camera and controlled by the computer; a complete set of alphanumeric characters is stored in memory for this purpose. In operation, each character is displayed on the CRT as a high resolution dot matrix, projected onto a masked area on the film frame, and registered in the transport shuttle. Use of this feature for frame count, date, or other notation avoids need for insertion of a scene-interrupting label frame; labels are fixed in size and position regardless of zoom or lateral negative positioning considerations.

Other functions, previously handled manually in the ATS equipment, are now completely automated. Automated camera functions include lens capping, shutter, zoom, fade-in, fade-out, up, down, forward, reverse, and lateral (rack over) motions. As before, the rack-over facility projects the reticle to show the area to be photographed. The source negative staging "compound" is also highly automated. The pin registry bar can be shifted laterally under computer control. The entire staging compound can be automatically shifted in X or Y in 0.1-mm increments, or rotated. A motorized platen on the staging compound is also computer controlled. A 30 x 30-cm glass opening in the compound contains an orthogonal grid template with lines spaced 2.5 mm apart. This "Machine Grid" permits the operator to enter position coordinates for both the compound and the negative-holding peg bar into the computer via a teletype terminal. One of the present hardware systems is shown in figure 10-1.

SOFTWARE AND PRODUCTION OPERATIONS

Under contract with Oxberry, NESS is developing the necessary process control software. As in the past, operational experience and changes in requirements suggest program changes. The current operational software represents a workable stage in the evolving operation. The earlier program development and the present operational software system are described below.

The first fixed program was for a "standard" production day. This program could produce, concurrently, nineteen film loops of fixed configuration from a preconfigured set of negatives. At this stage, a complete set of 30 consecutive negatives was expected to be available every day. A further assumption was that all negatives would cover the full Earth disc and would be available once every half hour. When actual production started it became obvious that more flexibility was needed, because a fixed number of consecutive negatives could not be expected; the negatives were a mix of full and half disc scans, and then infrared scans were added. Modifications resulted in a program capable of producing four types of film loops, with options for producing up to nine loops at a time in conventional "stop," "flow," or "alternate stop" loop form, and, for each loop, specifying the number of negatives, the starting negative, the X,Y loop coordinates, and the magnification setting. An overlay program permitted production of a specialized loop for commercial TV display. To guarantee fast software backup, a copy of the program was stored in a separate memory compartment not addressed during normal operations. This memory field could be accessed for program refreshing whenever the working software became contaminated or was destroyed.

This early effort satisfied the immediate needs but was not flexible enough to permit changes in operating format, type of loops, loop mixture, or the introduction of new loop formats. It was also very restricted in terms of the number of negatives that could be processed, and it could handle only nine loops at a time. Also, no room was available to include a correction for satellite drift, or many other desirable capabilities. As a result, a new program effort was begun.

The new effort differs in structure and philosophy in that software is now extensible and hierarchical in structure. A subroutine is available for the control of each of the stand's mechanical operations. These 'macro' instruction sets can be used individually to expose a frame, move the camera or the negatives, etc., or, on a higher level, they can be combined into structured 'building block' sequences. A building block can be a simple move-and-expose sequence, or it may comprise an entire loop production manipulation. On a still higher level, building block structures can be combined to form callable job structures. Any of the aforementioned can be retained or altered on-line by the operator or via paper tape from an off-line teletype. Additional capabilities include the ability to augment any loop with satellite drift correction and the ability to intermix half- and full-disc negatives.

To assist the operator and to minimize the chance for error, the program has an extensive conversational capability. This is divided into two parts. First is Computer Status reporting; here the computer types messages indicating deviations from standard status. Messages may, for example, report that the table is at an extreme position within its moving range, that a power supply has failed, or that there is insufficient light for exposure. Second, there is interactive capability, which guides the operator through a complete data input phase. The program requests all needed parameters and checks the validity of operator-supplied parameters. It will accept valid input or reject non-valid input and request corrected information.

The present software system, with its modular higher level language, provides a firm base for future operational changes. Consequently, improvements suggested by operational experience or required by mission changes can be added to the software package as needed.

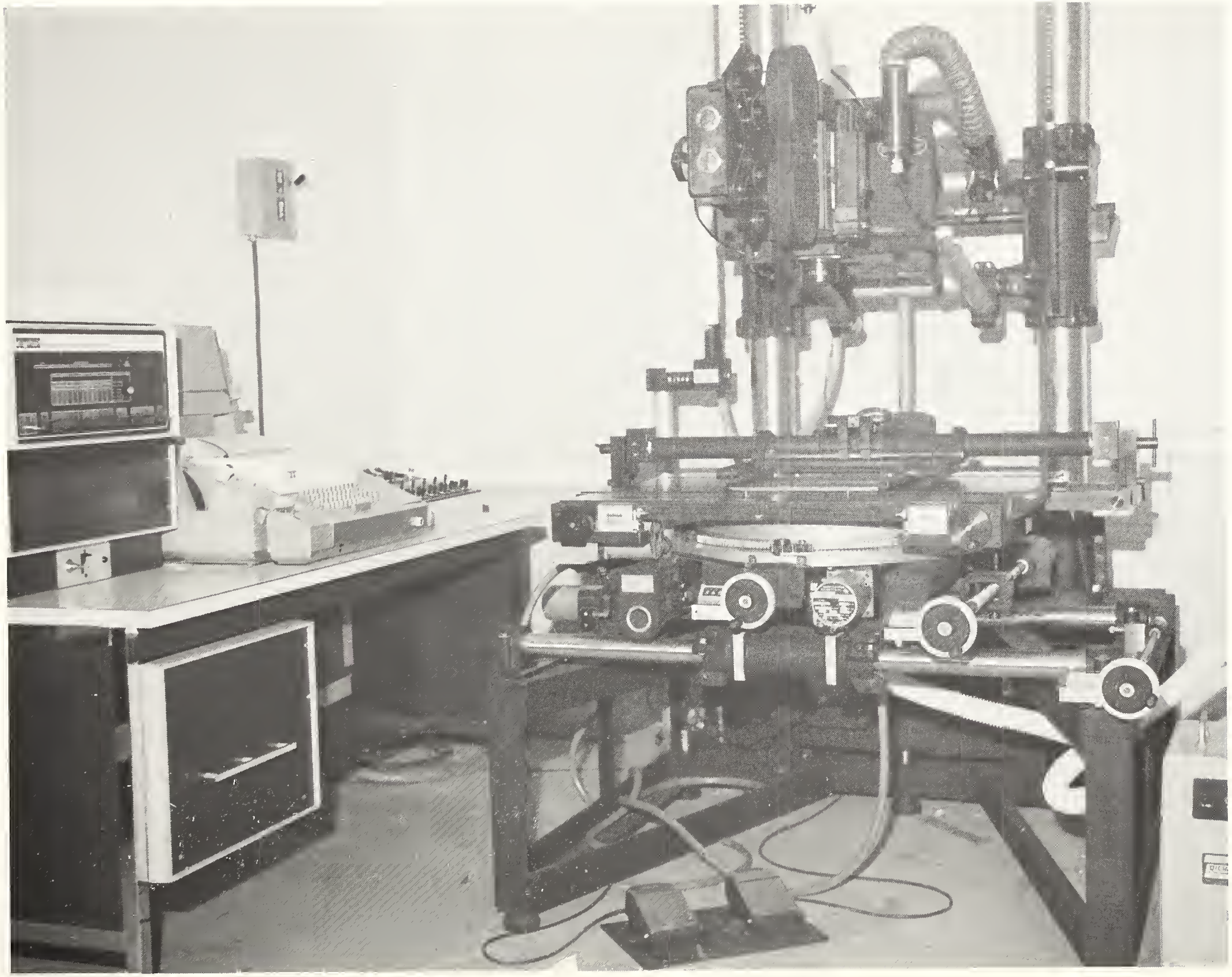

Figure 10-1.--Automated animation stand showing the Oxberry "compound" and camera mount. Controlling PDP-11 computer is at left.

11

THE MAN-MACHINE INTERACTIVE PROCESSING SYSTEM

R. E. Bradford, W. B. Waltham, and M. M. Kazmierczak

INTRODUCTION

The need for man-machine interaction arose directly from daily computer operations that require human intervention beyond the simple "GO NO-GO" decision. Procedural continuity and control, introduction of manually generated data (motion vector end-points, editing information, etc.), and display flexibility have become mandatory attributes of NESS computer-based operations.

As image data arrive for central processing, the procedure in which human extraction of information plays a part, usually involves the following steps:

1. The incoming bit stream is received, formatted, and otherwise minimally preprocessed by a dedicated ingest computer facility.

2. Buffered picture data are then used to produce image film and hard copy photo prints.

3. The analyst, using empirically derived standard procedures and judgemental decisions, extracts and records the desired quantitative information.

4. Extracted information is then manually entered into the central computer data base for utilization and ultimate dissemination.

5. As a part of the utilization, a variety of photo prints or other graphic products are generated for quality control, operational briefings, or subsequent study and research.

Apart from the analyst, two other groups of people are directly involved in the production cycle--computer operators and photo technicians. They make decisions which may be independent and somewhat arbitrary. On occasion, such decisions may alter or even terminate the data flow, even though their decisions are normally valid (as our present degree of success indicates). There is also the need to divert data to the photo lab and back. This introduces several opportunities for failure and inevitably injects degradations or distortions usually not found in a completely computerized approach.

Automation of such procedures minimizes the length of the data flow path and, more importantly, restricts the existence of the data only to a finite number of states in a predefined environment. This limited number of states not only provides single-source data for all users but also simplifies and makes practical the recovery of data through transformation from an unusable state to a usable state since each state has defined and controlled attributes.

Many of the decisions, information extraction processes, and dissemination procedures--all of which provide the "glue" that holds the procedure together--may be automated. However, too many of these activities have defied definition by objective rules and so require the judgment of highly trained human analysts. The analyst, with his sophisticated and efficient information discriminator skills, can assimilate massive amounts of data and extract only information that is relevant, e.g., vector end-points from loop movies. The human is also the most knowledgeable interface with the world outside of the automated procedure and, hence, is in a position to introduce control information and supplemental data into the procedure for optimal production.

The Man-Machine Interactive Processing System (MMIPS) is our approach to introducing human expertise into an automated procedure. Those relatively few cases in which all conditions are predefined are handled by computers. Those more complex cases requiring analyst skills are handled through specially designed interfaces. One end of MMIPS interfaces with the human, the other with the computer complex. Its basic job is to transform computer-stored data into information understandable by the human and vice versa. MMIPS is, thus, a highly sophisticated communications device whose internal data processing functions translate from one "language" into another.

PROCUREMENT, DESIGN, AND DELIVERY

Emphasis in hardware procurement was placed on display capabilities, real-time processing, and computer-to-computer linkage in a station facility at which an analyst could conveniently and comfortably carry out his function. The configuration of the delivery system is shown in figure 11-1. In addition to a rather standard configuration (central processor unit, memory, line printer, card reader, teletype operator's console, and magnetic tape units), there are the special features, which include a real-time clock, disk storage, keyboard with alphanumeric CRT display, continuous tone video-display system, and a data adapter for intercomputer linkage to the dual IBM 360/195 system. Figure 11-2 provides a view of MMIPS and the microwave link connecting the remote MMIPS facility to the large computer complex.

The unique feature is the video display system and the interactive support provided by the keyboard CRT. A 25-in CONRAC color monitor is the primary video display component. The refresh storage is a set of digital disks capable of holding six 4-bit frames (512 x 512 picture elements) or four 6-bit frames plus a graphics overlay (1-bit) track. The controller connects a set of tracks holding a particular frame to the display. In the black-and-white mode, the signal intensity represented by the 4- or 6-bit value is delivered equally to each of the three color guns to produce a gray shade display. If pseudo-color capability is activated, the digital value (0-63) is used as an address to fetch a set of intensities that is delivered to the three CRT guns. If the graphic overlay is activated, it will be combined with the imagery to produce a spot (white if the local image intensity is low or black if intensity is high) wherever a graphic overlay bit is set to 1. If the track ball/target (TBTG) is activated, a small diamond-shaped marker is generated and is displayed effectively in the same way as the graphic overlay. The position of the target marker is changed by moving the track ball. Other features include a split screen mode (either vertical or horizontal) with one-half of the display area supplied from one frame in the video refresh disk and the other half from any other frame, and a "roll-up/roll-down" mode that permits vertical rotation of the displayed frame, one line at a time.

The most important aspect of this display system is that all of the above functions are addressable by software through the controller. These optional features may be turned on or off or changed during sync times, which permits a great deal of flexibility in controlling the actual display.

The keyboard-related CRT for alphanumeric display is used to interact with the command analysis routine to permit the analyst to display desired character information. It is also used to interact with numerical data. Figures 11-3 and 11-4 are photographs of the equipment.

Software delivered as part of the system includes an Input/Output (I/O) control system. It contains driver routines for all peripheral equipment, a file management system that maintains a structured file system on the primary disks, a data management system that facilitates data movement from one storage device to another, an acceptance test program which demonstrates the hardware capabilities, a DOSS (Day One SMS System) program to assist in determining cloud temperatures, and a number of other utility and diagnostic software routines.

The test program is currently used for landmark location determination, calibration data collection, system demonstrations, and other functions. The DOSS program is used operationally with film loops to assign temperatures (which are later transformed into heights) to cloud motion vectors. All of these use functions are extremely valuable and demonstrate the utility of the hardware system even when used with relatively primitive software. Software now under development to exploit full hardware capabilities is described in the folowing section.

MOTIVATIONS AND DEVELOPMENTAL ACTIVITIES

MMIPS is intended to provide a means for an analyst to enter into the processing of mass data normally performed by large computers. The primary intent is to develop operational procedures that permit routine generation of data in support of NESS and NOAA missions. Although R&D

activity is of secondary priority, it is of extreme importance in the realization of longer term goals and so is fully considered in the development of MMIPS.

There are three rather near-term projected uses that provide the immediate motivation for development:

WIP - Winds Interactive Processing, which is intended to replace the need for film loops and include the temperature determination technology being developed for DOSS;

ACLOWIN - a full integrated Advanced Cloud Wind system that includes manually as well as picture-pair produced winds, and the interface with the NOAA central computer data base (NMC data, etc.); and

SIP - Soundings Interactive Processing, which permits the analyst to offer judgment in SST and VTPR type processing of polar orbiting satellites.

Each of these procedures represents not only a significant advance in interactive processing but a big step forward in our ability to provide high quality observational data sets for dissemination to and utilization by other NOAA organizations.

WIP provides the ability to present large data volumes to an analyst for information extraction without hardcopy penalty. Not only is animation a feature, but WIP also provides the ability to rapidly affect image presentation through gamma function variation and pseudo-color flexibility. Since all data are retained in the computer, the analyst no longer need concern himself with clerical functions such as punch card handling or other hard copy manipulation.

ACLOWIN, which includes WIP and requires the development of another major procedure that we call VET (Vector Editing Technology), represents a major system integration effort. Data from several sources, e.g., raw ingest data files, NMC analyses, orbital parameter predictions, and picture-pair wind fields, are brought together to generate a homogeneous wind field observation set. This set is then transferred into a central computer data base for utilization by those who require wind data.

While WIP and ACLOWIN represent the processing of geostationary satellite (GOES) data, SIP introduces new concepts for the processing of polar orbiting satellite data. In this case, the analyst will "ride" the satellite while "seeing" the earth in imagery created by resolving the dual channel SR data and the VTPR instrumentation. The analyst will have the ability to "put on the brakes" for a longer look at any selected section and start up again when he is satisfied. Sea surface temperature information from VISSR data may later become an alternate information source in this development. Although these three efforts certainly present intriguing challenges, there are indications that more developments are coming. It is expected that capabilities resulting from these three developments will generate new and more advanced concepts for future development.

The system, comprising three MMIPS stations connected to the NOAA central computer facility, constitutes a network, of sorts, with four nodes. The IBM 360/195 node is the interface with NESS and other NOAA data bases, with VISSR ingest data files, ITOS data, and with operational programs. It is the primary data source for MMIPS. Since the interaction at each MMIPS station is with a man and the interaction in the IBM 360/195 is automated, we feel this is a powerful and most flexibile system available for any such future developments.

With respect to the software system, there are two basic approaches. One is to develop each application, e.g., WIP, as a separate program. This would assure that the functioning is streamlined, but the interaction between application developments would be extremely difficult. The nature of the 360/195 node would be overly complex when considering the need to change from one operation to another during the course of a day's work. This led to adopting the second approach, which is to build a basic system to serve as the environment for all applications. All developed functions are available to all applications or procedures. The general sense of this approach is that all development is upward rather than in parallel. This also permits development of "stand-alone" capabilities at each node which can later be integrated into a full system procedure.

MMIPS IN THE ON-LINE ENVIRONMENT

With linkage to the IBM 360/195 only recently accomplished, much remains to be done before we attain a smooth direct-coupled operation. The following detailed descriptions of the system are therefore partly projective.

To compartment task assignments, it is convenient to separate the system into three parts: the station facility, the large-scale computer portion, and the command and display facility.

The analyst's station facility portion deals mainly with the local minicomputer, and contains software modules that have "stand-alone" performance capabilities. The station facility system can be compared to a peripheral controller with several devices. A simple analogy in terms of functional independence is: a card reader does not require a printer to be on-line to read a card, nor does the printer require the card reader for printing a line. However, a practical function requires both reading a card and printing, which is a system function. This reasonably resembles the system module interactions. In this context there are five modules to accomplish command analysis, dynamic display, dynamic file service, large-computer interfacing, and minicomputer support. Dynamic display and the latter two of the above all represent data source/sink functions, and the dynamic file provides the internal "staging" service which interacts with all incoming or outgoing data. The command analysis module provides the primary path for source control information from the analyst.

Inter-communications between the modules are accomplished with control messages passed by a routine within a communications executive program which is the overall software manager for each station facility. Message types include: INITIALIZE (get ready); STATUS (give the indicated status); REQUEST (perform a function, e.g., magnetic tape read or write); and RESPONSE (interrupt, for example, after completion of a function). A fifth message type, POLL, involves multi-modal modules and allows service linkage internally inspired tasks. Executive supervision and message passing is done by means of a polling routine which makes "rotary" contact without special priorities. Equitable distribution of minicomputer resources is thus achieved, and, when no tasks are waiting for service, the system continues in this "idling loop."

The advantages of this modular approach are relatively obvious:

1. The only external functions required for a system module to operate are those provided by a minimal executive program; thus, degraded modes are definable and practical;

2. New modules may be added without affecting existing operations;

3. New functions may be added to existing modules without affecting current operations;

4. Several system "configurations" (of modules) may exist compatibly, e.g., operational, test, and developmental; and

5. External hardware equipment may be used almost indiscriminately.

The greatest disadvantage is probably that the implicit flexibility requires a great deal of careful thought to provide a useful finite system. This is most crucial in the command analysis module, which interfaces with the analyst.

Although the station facility system and the large central computer are vital components, the command and display subsystem is central to the purpose of MMIPS. It is therefore the most important component since it provides the analyst interaction pathway. Being manual and visual in nature, it is also the most visible component.

In general, the analyst will issue commands that will be translated into work functions throughout the system. These commands will normally require the display of data and will set a system state that will permit the analyst to alter the displayed data or to enter other information related to the displayed data. The displayed data are in the form of imagery (still or animated) and numerics (raw data or derivatives). These displays are primarily "soft" copy CRT images. There are provisions for "hard" copy in the forms of printed pages and magnetic tape.

The commands available to the analyst exist in three levels of complexity: basic, intermediate, and highest (or procedural). The basic command sets imply the most rudimentary, one step at a time, functions, e.g., read a data file into memory or load a table into the display system from memory. The intermediate commands are commonly used combinations of the basic commands, e.g., load an image into the display system from a disk file or edit a table. The highest level commands are combinations of intermediate and basic commands patterned into a procedure that represents a complete analyst function, such as a wind extraction operation.

While the difference between basic and intermediate commands is mainly a matter of convenience, the step up to the procedural command is large and functional. A basic or intermediate command may be given at any time and the system will try to satisfy it, given the present state of the system. If there are prerequisities that are not satisfied, the command will simply be rejected. The analyst is responsible for preparing the system for each command by issuing a logical sequence of commands. The procedural command is significantly different in that the system, upon receipt of the command, initializes itself and begins stepping through the "pre-stored" set of lower commands. The analyst is continuously informed of what the system is doing and is required to enter "hand" data on request. At this point, the system is, in essence, issuing the commands and the analyst must respond.

This "turning-of-the-table" implies a great deal about the development of a procedural command. In order for the analyst to accept this subservient position, we must have earlier devised the proper procedure. Thus, the means by which the analyst may realize the full power of MMIPS is relatively clear. He must lay out a structure of lower level commands, step through them manually to verify the results, and formalize them; this includes designating mandatory and optional steps or parameters. This manual procedure is then translated into system terminology and given a procedure name. WIP, ACLOWIN, and SIP are examples.

Support from the large dual IBM 360/195 computer facility is the final supporting system ingredient for MMIPS. Since Callicott has discussed that system in the first portion of this memorandum, only the direct linkage and analyst interaction will be discussed here.

The software by which the analyst makes requests and the IBM system supplies desired information and calculation support is called the MMIPS Large Computer System (MLCS). Each is capable of functioning independently. Subsystems intercommunicate via the LCSMP (Large Computer System Message Processor) modules. This software module accepts and holds requests for work to be done and responds by either activating the subsystem or by passing it. A discussion of each system module follows.

The Large Computer Executive Component has several diverse responsibilities:

1. Communication with the IBM-360 operator.

2. Defining the 360 configuration during MLCS restart.

3. Supplying other subsystems with information from the IBM Executive Operating Software System such as time of day and internal timing.

4. Keeping a record of both internally and externally generated inter-subsystem requests as a summary of processing.

The Data Acquisition System is the path by which the 360 system acquires data from the primary VISSR data ingest files to supply input for MMIPS operations. By accessing VISSR source data files on a scheduled basis, this software component insures that the MMIPS data base contains the current data needed to run a scheduled operation.

A Data Management component performs several functions: the retrieval of material from the MMIPS data base for processing; determination of data base structure at initialization time; and creation, update, and retrieval of temporary data files produced during the processing.

Since the MMIPS systems does not exercise any control over the workload within the 360 system, another subsystem module has been included as a protection against outage. Recovery Management module provides: error or exceptional condition analysis; procedures for fail safe, suspension, or restart when problems arise; acquisition of checkpoint locations for restart assistance; and on-line debugging and system maintenance facilities.

With the microwave linkage between the 360 system and the three operating station nodes, another Interconnect System module permits the exchange of information. This program, resident within the 360, receives data orders and processing requests from each station, and returns information regarding processing status. It also sends and receives buffered data.

Another module is the Cross File Processing program which may be considered a library of processing programs evolved in response to analyst requests. One such module is resident within the 360 for each node station. The library routines in each perform functions such as data response, range conversion, and scaling. By maintaining separate service for each analyst, we retain the option to have each Cross File Processor configured for a specific operation.

The final module is an External Communications Processor that enables the analyst to send information to or receive information from permanent disk files. These exchanges are set apart from raw VISSR data exchanges since they involve processing results which are to be passed to another 360 program or may be results of another 360 program which are needed temporarily by MMIPS.

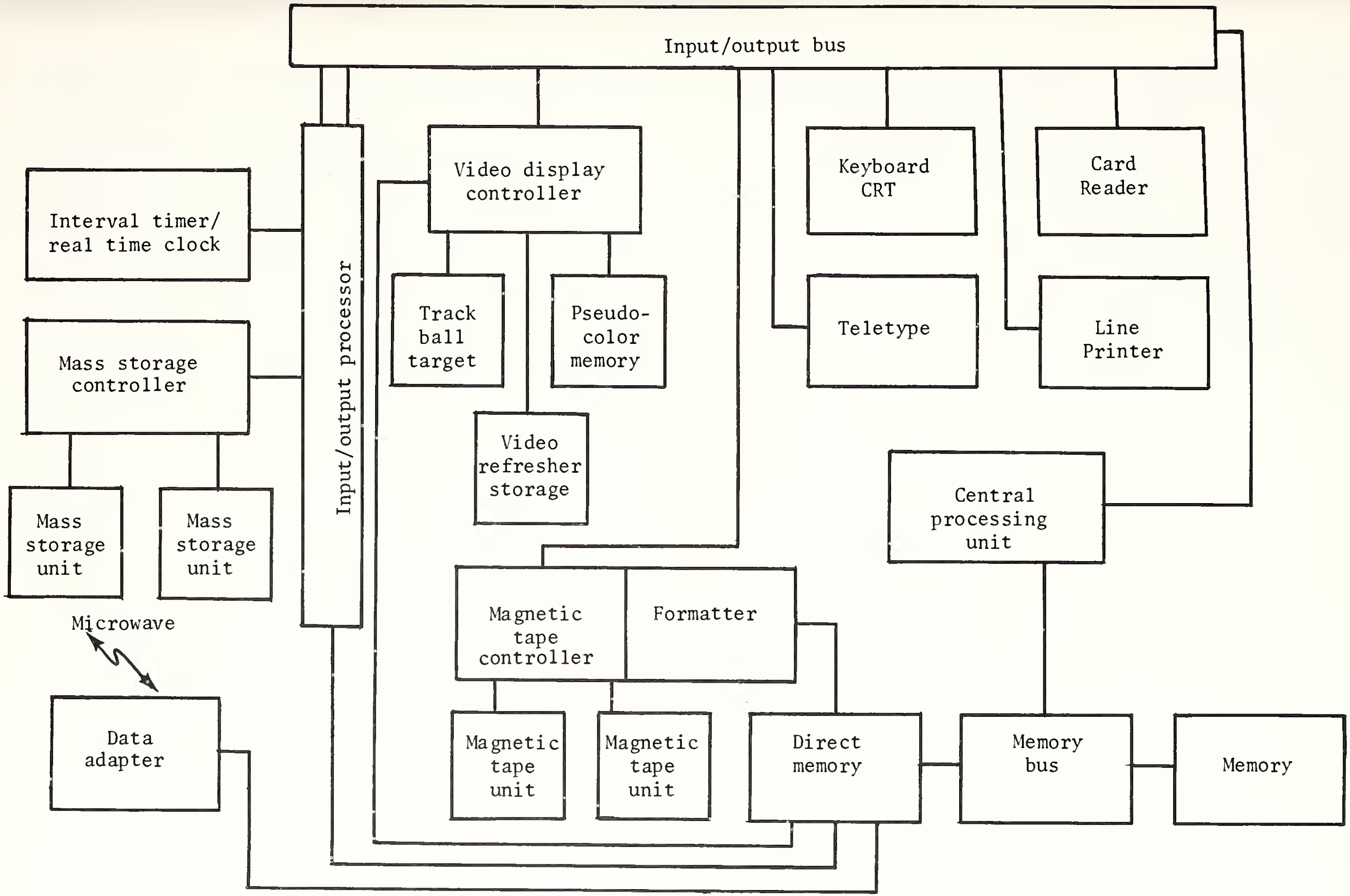

Figure 11-1.--MMIPS Station Facility configuration

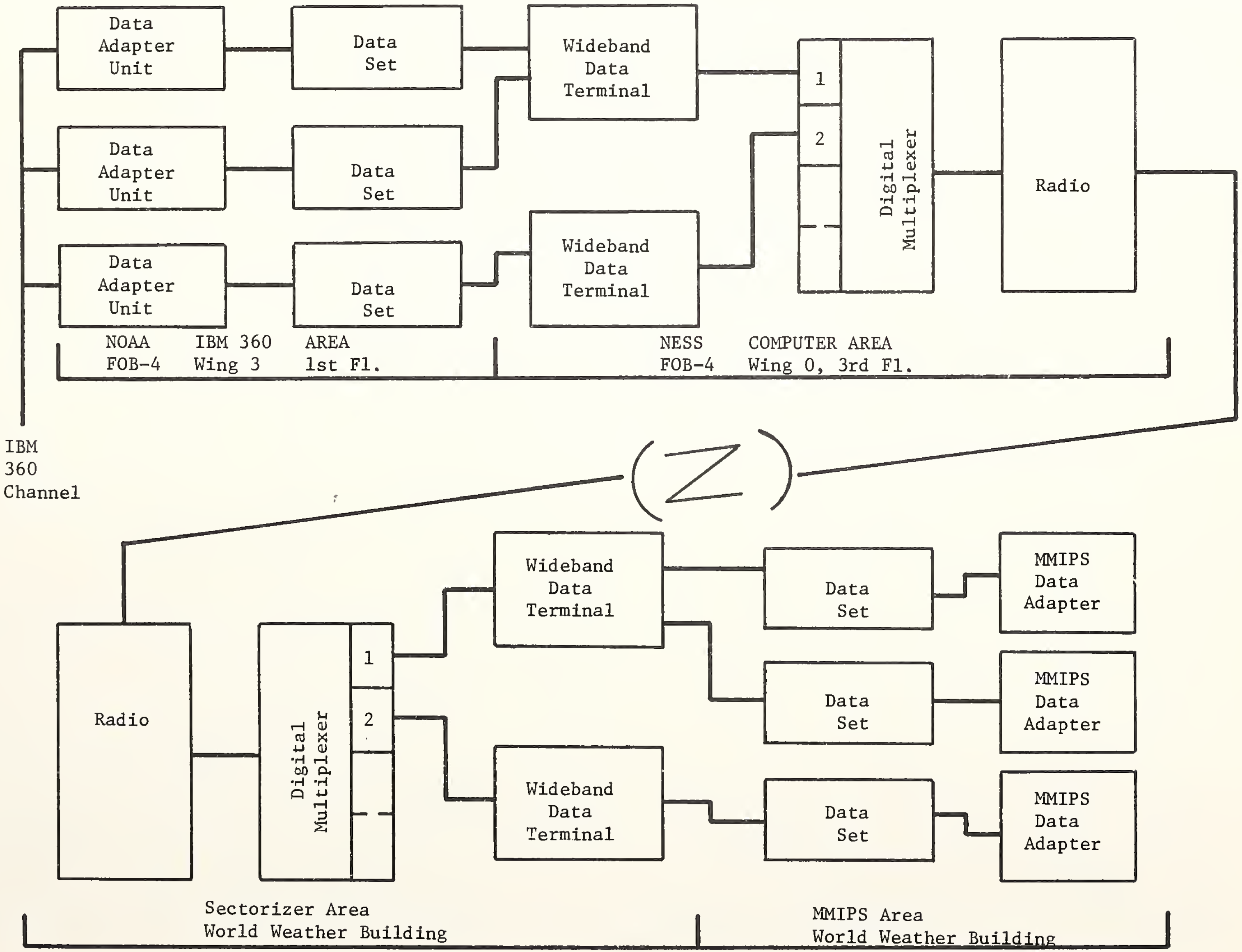

Figure 11-2.--MMIPS-IBM 360 microwave interconnection

Figure 11-3.--MMIPS configuration (l to r): Keyboard/alphameric CRT; color imager CRT; teletypewriter; GTE minicomputer, tape units, line printer, and card reader. Not shown--two 22-M byte Ampex disk units.

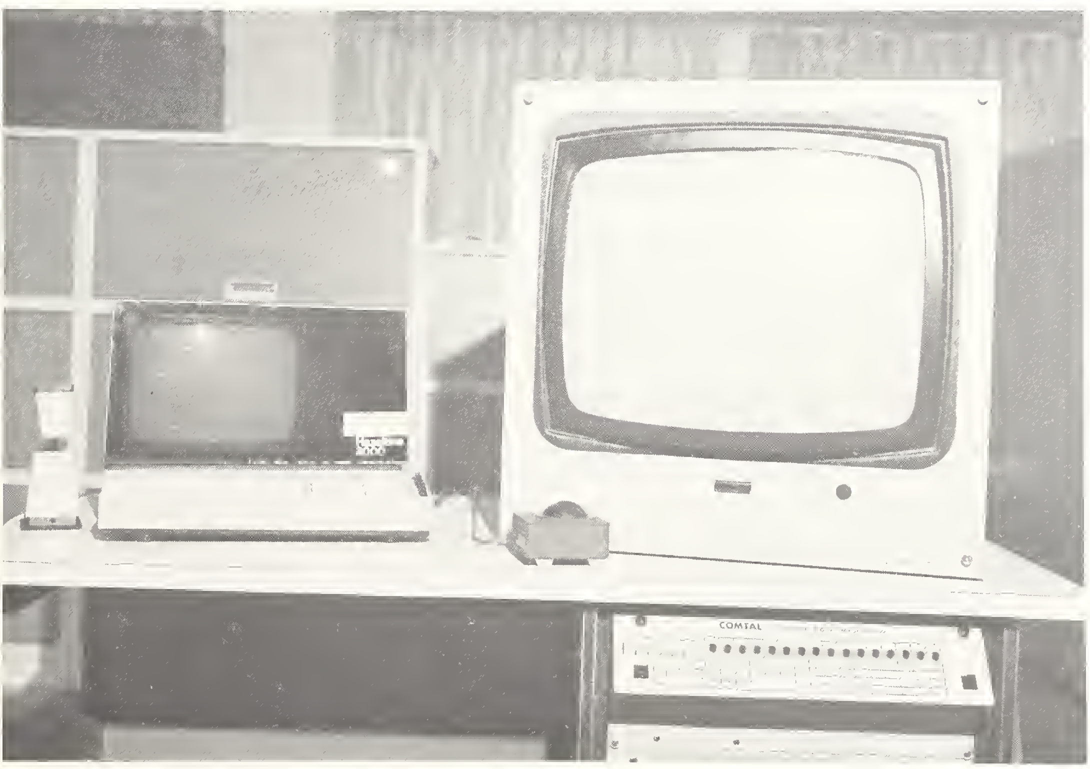

Figure 11-4.--MMIPS CRT units including track ball and display controls

12

THE AUTOMATIC EXTRACTION OF WIND ESTIMATES FROM VISSR DATA

R. Green, G. Hughes, C. Novak, and R. Schreitz

INTRODUCTION

Cloud motion vectors have been derived in daily operations since 1969 by viewing animated sequences of cloud pictures and manually fixing the positions of cloud elements at the beginning and end of the picture sequence. The details of the procedures are described in paper 13 of this memorandum. The feasibility of measuring cloud motion vectors with computer methods has been demonstrated for a number of cases (Bristor et al. 1967, and Leese et al. 1970), and an automated operational procedure for measuring low-level cloud motion vectors from ATS data has been described and demonstrated by Bradford, Leese, and Novak (1972).

The launch of SMS-1 in May 1974 provided a source of improved geostationary scanner data. The experience gained over a period of five years of experimental and operational processing of ATS-1 and ATS-3 data provided the expertise for adapting automated winds extraction techniques to VISSR data. Automated extraction of low-level wind estimates from SMS-1 data began on August 19, 1974. This automated operational procedure requires, in addition to a valid measurement technique, the ability to register the pictures precisely, to detect valid areas for making measurements, and the exercise of quality control procedures over the numerical values obtained from the measurement process.

THE MODEL FOR LOW-LEVEL VECTORS

VISSR data flow and details of sensor channels and sample formats are given in papers 1 and 8 of this memorandum. Model inputs from the VISSR ingest computer consist of interleaved IR and visible channel data for the entire Earth disk. IR sampling is overlapped (4 x 8 km) so that 3822 picture elements are obtained for each scan. The same volume of nonoverlapped visible channel samples (4 x 4 km) are obtained in record pairs for each scan.

A generalized diagram (fig. 12-1) shows the logic of the model. Although the model uses only two pictures as input, three successive pictures, 30 minutes apart, are ingested to provide a backup in case processing problems arise. Picture pairs 30 or 60 minutes apart are suitable for input to the model.

The preprocessor performs the following functions:

1. Coincident visible and infrared scan lines are separated, and separate visible and infrared picture data sets are filed on disk for processing on a large scale computer.

2. Geometric documentation inputs are used in an algorithm which establishes the Earth disk center coordinates within the entire sample array.

3. Diagnostic checks are made to detect format anomalies, such as line dropout or scan count errors.

Earth location of open arrays of image sectors is also a part of the preprocessor. Once image coordinates have been normalized with reference to the Earth disk, the sample and line locations are calculated for a preselected array of latitude-longitude points, using a variation on the approach employed in image mapping and gridding (discussed in papers 5 and 6 of this memorandum).

Once the Earth located visible and IR channel image pairs (figs. 12-2 and 12-3) have been obtained, they must be more precisely registered for accurate measurement of cloud motion vectors. This important alinement improvement to the first stage time-attitude-orbit location calculations is obtained by using cloud-free landmarks (control points). A sufficient number of cloud-free features are found within the wide expanse of the image scene. Semi-arid regions such as the salt desert in Bolivia provide good targets; this feature appears as a bright region in figure 12-2. A unique point near 20.5°S and 67.5°W is shown in a detailed map of this area (fig. 12-4).

Using this target feature as an example, the first step in the precise alinement procedure is the standard Earth location calculation. Figure 12-5 is an alphanumeric display of the salt flat feature as specified by time, attitude, orbit, and latitude-longitude inputs. The 64 x 64 line-sample array indicates a geographic location error since the selected feature (denoted by "+") is not found at the center of the array (denoted by "⊕"). With imperfect preprocessor inputs, such small but important errors are typical. If, as in the usual case, such errors differ, then cloud displacements may contain considerable errors both in direction and speed. Although such precise registry deals with small residual errors, it is nevertheless an important correction to be applied to all cloud vectors. Investigation has shown that this small residual error is linear with respect to the line-sample image realm within which vectors are to be generated. A combined landmark processing technique, therefore, has been developed by which a single correction vector is generated for application to all cloud displacements. Using an SMS-1 picture pair obtained at 1030 and 1100 GMT on November 2, 1974, as an example, the steps in the procedure are:

1. Forty-two predetermined landmarks were chosen from the SMS-1 field of view.

2. Using preprocessing information, orbital elements, and attitude for each location, a 64 x 64 line-sample array is extracted from each picture of the pair.

3. Cross-correlation matrices[1] are computed forward ($t_0 > t_1$) and backward ($t_1 > t_0$) in time for each landmark location in the following manner:

a. A 32 x 32 subset centered in the middle of the 64 x 64 array at t_0 is correlated with the 64 x 64 array at t_1.

b. A 32 x 32 subset centered in the middle of the 64 x 64 array at t_1 is correlated with the 64 x 64 array at t_0.

4. For each correlation matrix, the lag values of all relative peaks and neighbor coefficients within 0.005 of the peaks (chosen empirically) are determined. The lag value positions from the largest maxima are accumulated in a primary frequency distribution. The lag value positions associated with all other maxima are accumulated in a secondary frequency distribution. The distributions shown in figures 12-6 and 12-7 contain the final results for the primary and secondary frequency distributions after all cross-correlation matrices have been processed.

5. The primary distribution is searched for the maximum frequency of occurrence, which in this case is located at lag value -1, 0; this is used as a first guess.

6. The fields of primary and secondary distributions are added. From a 3 x 3 array centered about the first guess position (-1,0), the center of mass is determined. This value is the refined registration error (-1.07, -0.04).

The unique peak found in the primary distribution shows the consistency of the relative registration error. Secondary peaks are useful when landmarks are partially cloud covered since either peak may represent the displacement depending upon the extent of the cloud cover. The computation of the cross-correlation matrices forward ($t_0 > t_1$) and backward ($t_1 > t_0$) in time for each landmark is useful in the case of large mislocations in one of the pictures. For example, it is possible that the landmark may be located in the 32 x 32 subset at t_1 and in the 64 x 64 array in t_0 but not in the 32 x 32 subset at t_0. A valid registration error would be determined from $t_1 > t_0$ but not from $t_0 > t_1$. Lag values having coefficients within 0.005 of the peak are considered as true peaks. The reason is that noise may dampen the true peak in areas of flat gradients and possibly may displace it by a lag value.

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[1]The measurement algorithm used to compute landmark displacements is cross correlation using the Fast Fourier Transform method. These procedures are described by Leese, Novak, et al. (1971) and Leese and Novak (1972).

The cumulation of lag values having the above criteria from matrices computed forward and backward in time will reinforce the true peak.

The final result of this procedure is an accurate but slightly mislocated vector since no attempt is made to correct any remaining geographical error in the absolute sense. The importance of these registration procedures cannot be overemphasized; a misregistration by one sample of two pictures 30 minutes apart can result in a vector error of approximately 7 kt at the subsatellite point.

Cloud target selection is the first step in the selection and measurement portion of the picture-pair model. In this step, each image sector array is presumed to contain a sufficient number of internal topographic cloud image features so that disregarding such features at arbitrary sector boundaries has little influence on subsequent measurements. With this assumption, image sectors are preselected at 2.5° latitude-longitude centers; this permits the obtaining of hundreds of wind estimates for numerical weather analysis and other macroscale synoptic applications. Each target sector consists of a 32 x 32 sample array. At this stage, each preselected sector is regarded only as a potential measurement candidate. Further checks are made to determine eligibility as a cloud vector data source, and post editing procedures are used to delete measurements from invalid target areas.

A target selector using multiple discriminate analyses procedures (Booth, 1972) was developed to determine whether the visible satellite imagery located at a particular grid intersection could produce a valid low-level motion vector. Initial experiments showed this could be accomplished 70% of the time. Significant improvements in this accuracy would require normalizing the pattern parameters for solar zenith angles. The post-editing procedures produced results equal to and sometimes better than the results obtained by using the target selector. Since normalizing for solar zenith can be a costly procedure in computer time, it was decided to rely on post-editing to delete measurements from invalid targets. The target selector approach is more applicable to the infrared data, so development has begun in that area.

The cloud displacement measurement is the core of the model. It represents refinement of a basic displacement algorithm which may be described in three steps:

1. For each selected location, a 32 x 32 image sample array is extracted from the earlier picture and a companion 64 x 64 array is extracted from the later picture.

2. Cross correlations are made for all possible positions of the small array within the larger one (1089 correlation computations)

3. The lag value position of maximum correlation is selected as the cloud displacement measurement.

The refinement of this basic technique, termed the First Guess/ Fast Displacement Algorithm (FG/FDA), is currently in use operationally. A "first guess" vector, $\overline{V}g$, is obtained from the NMC 850-mb analysis and the time difference, dt, between the two pictures to define lag value bounds for a sub-array, S, in the 33 x 33 array of correlations, A, so that S will contain

1. an ellipse E which has the following property:

$$|\overline{V}(dI,dJ) - \overline{V}g| < |\overline{V}_e|,$$

where $\overline{V}(dI,dJ)$ is the velocity vector computed from the lag values dI and dJ, for all dI and dJ in E, or, more simply, the error speed is less than the error speed limit $|\overline{V}_e|$; and

2. a frame F of arbitrary width k which surrounds E (fig. 12-8).

For a time difference of 30 minutes, an error speed limit of 24 knots, and a frame width of 1, S is typically only 15% as large as array A. Thus if a "valid peak" can be located after these initial correlations have been computed, a substantial reduction in overall processing time will be realized. A "candidate peak" is defined as the highest correlation computed in sub-array S, and a "valid peak" is defined as a candidate peak when, for its associated lag values dI and dJ,

$$|\overline{V}(dI,dJ) - \overline{V}_g| < |\overline{V}_e|.$$

Approximately 80% of all the vectors computed are processed through the FG/FDA procedures. If the foregoing relation does not hold, the remaining correlations will be computed and the lag values corresponding to the highest correlation in the completely filled correlation array will be used to compute the velocity vector. In essence, the procedure reverts to the basic displacement algorithm. The cross correlation method used is based upon software procedures obtained from the Laboratoire de Meteorologie Dynamique, E.N.S. Physique, Paris, France. These procedures have been modified for optimal processing on the IBM 360/195 system. Once the velocity vector has been computed, it is transformed into an Earth oriented low level wind estimate.

The third portion of the model involves quality control, and as indicated in figure 12-1, a portion of this control is done manually (see paper 13 in this memorandum). However, a substantial role is played by a Post Editor program.

The automated Post Editor provides vector editing in two major steps. First, obviously erroneous vectors are screened (rejected) by comparing the computed vector with the NMC 850-mb wind at the same location. If the absolute speed difference between the computed vector and the 850-mb wind speed exceeds 30 knots, the vector is rejected. Second, if the vector passes the initial screening, it undergoes three independent quality tests. The tests consist of a First Guess (FG) check, Parameter Screen (PS) check, and a "Buddy" Check (BC). A pass/fail indication is given by each test and, depending on the results of the three tests, each vector is either assigned a Quality Index (QI) or is rejected. The QI is defined as the percent probability that a meteorologist/ analyst would accept the given vector as meteorologically sound, i.e., a vector assigned a QI of 90 would be accepted by an analyst 90% of the time, on the basis of past statistics. A brief description of the three tests follows.

The FG check uses the 850-mb analyses to compare the direction and speed of the computed vector with that of the 850-mb wind. A vector will pass this test when its direction and speed differ from the 850-mb wind by less than 60 degrees and 16 knots.

Next, the PS check uses empirically derived relationships based upon parameters associated with the vector computation (magnitude of the maximum calculation coefficient, the ratio of maximum correlation coefficient to its surrounding neighbor values, and standard deviation of the brightness in the search area) to discriminate "good" from "bad" vector measurements.

Finally, the BC test compares the computed vector with its immediately adjacent neighbors. The vector passes this test when it agrees with at least two neighbors within 60 degrees in direction and 16 knots in speed.

Assignment of a QI or rejection is based upon the following criteria:

Tropics (20°N - 20°S)		QI (%)
Pass	FG + PS + BC	96
Pass	FG + BC or FG + PS	90
Pass	FG only	84
Pass	PS + BC	72
Pass	PS or BC only	rejected
Fail all three tests		rejected

Extratropics (20°N - 40°N and 20°S - 40°S)		QI (%)
Pass	FG + PX + BC	93
Pass	FG + PS	81
Pass	FG + BC or PS + BC	72
Pass	FG only	67
Pass	PS or BC	38
Fail	FG + PS + BC (Fail all three)	rejected

The vectors surviving after post-editing reside in a computer disk file. In support of the subsequent hand editing process, the vectors are mapped on a Mercator map base and a digital tape is written in facsimile display format. Figure 12-9 shows the mapped vectors derived from visible channel data for November 25, 1974.

EVALUATION OF THE OPERATIONAL MODEL

The model described above became operational on August 19, 1974. SMS-1 VISSR data from 1030 and 1100 GMT were used each day as input;

1000 GMT data were used as backup. The operation was expanded to twice per day on November 18, 1974. Picture-pair data for 1600 and 1630 GMT are used with 1530 GMT data as backup.

System performance is defined in terms of quality and timeliness. Quality is determined by the final manual evaluation of the vector product and timeliness is a function of deadline times defined by the final user (NMC). For the period August 19, 1974 through November 30, 1974, the reliability of the operations was 87%. The thirteen percent failure-to-process rate can be divided among the following problem areas:

1.	360/195 Hardware and Systems	5.6%
2.	Human error	5.6%
3.	Miscellaneous	1.8%
		13.0%

Man and machine problems are approximately equal. On the human side, operator errors accounted for somewhat more failures than did programmer errors. Software problems tend to decrease through program usage, so the major effort in improving performance is being directed at system design which relates to both operator and hardware problems.

Present efforts, in both hardware and software, will result in a more direct coupling of NESS-dedicated facilities and the dual 360 system. Specifically, nine mini- and midi-computer systems are being direct-coupled through four 320-K byte channels, so that tapes now hand carried and remounted for data transfer will be used infrequently as backup only. Effort to maintain good interface compatibility between tape drives will then be reduced, and the chance for mismounting tapes also will be lessened. A related effort involves a more direct linkage between the MMIPS and the 360 system. This will permit the elimination of hard copy wind vector plots in favor of a more direct and interactive editing operation. Although the direct coupled operation may present other problems, the expectation is the picture-pair operation will achieve a performance score of 95% or better.

DEVELOPMENTAL PICTURE PAIR ACTIVITIES

The availability of infrared data from geostationary satellites affords the opportunity to expand our meteorological knowledge and extract more quantitative information. In terms of the automated approach, techniques are being investigated using a target analyzer to determine:

1. Upper- and lower-level thermal slice profiles within the target arrays,

2. temperature-height estimates for the selected slices, and

3. wind estimates derived from displacements confined to the individual slices.

A model designed to perform the functions listed is currently being tested and evaluated. Realistic evaluation has been hampered by lack of adequate "ground truth." In addition, sensor calibration problems have prevented proper techniques evaluation. These problems are being worked on and practical solutions should be found in the near future.

CONCLUSION

The model has performed reasonably well during the first 110 days of SMS-1 picture-pair operations. The Preprocessing, Selection and Measurement, and Quality Control Units performed their functions, when not hindered by hardware problems and human error, with a high degree of reliability. Development has begun and will continue in the use of infrared VISSR data. One infrared model that will provide wind and temperature/height estimates for lower and upper levels has been designed and is undergoing testing and evaluation.

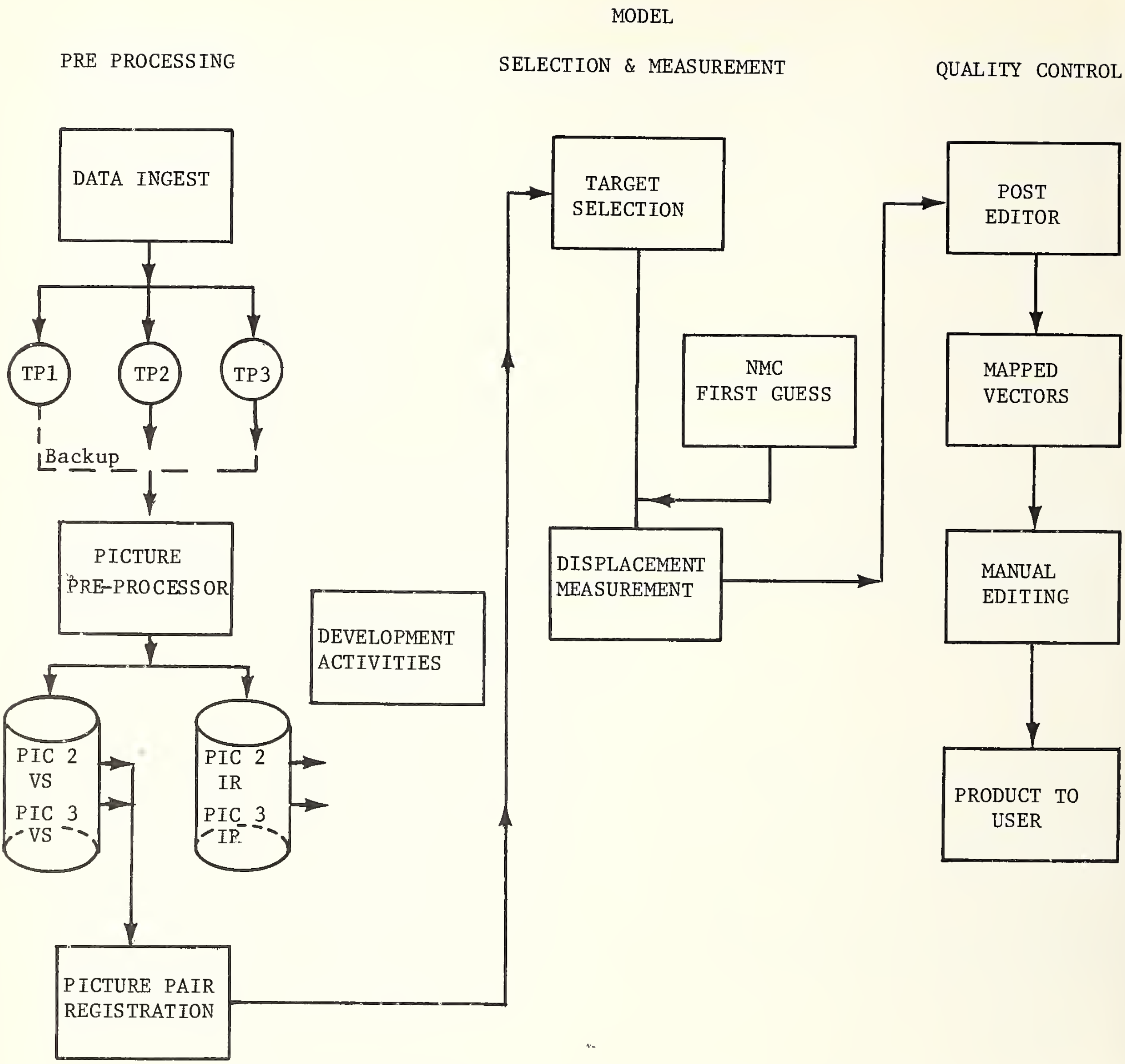

Figure 12-1.--Cloud picture-pair motion model and data flow

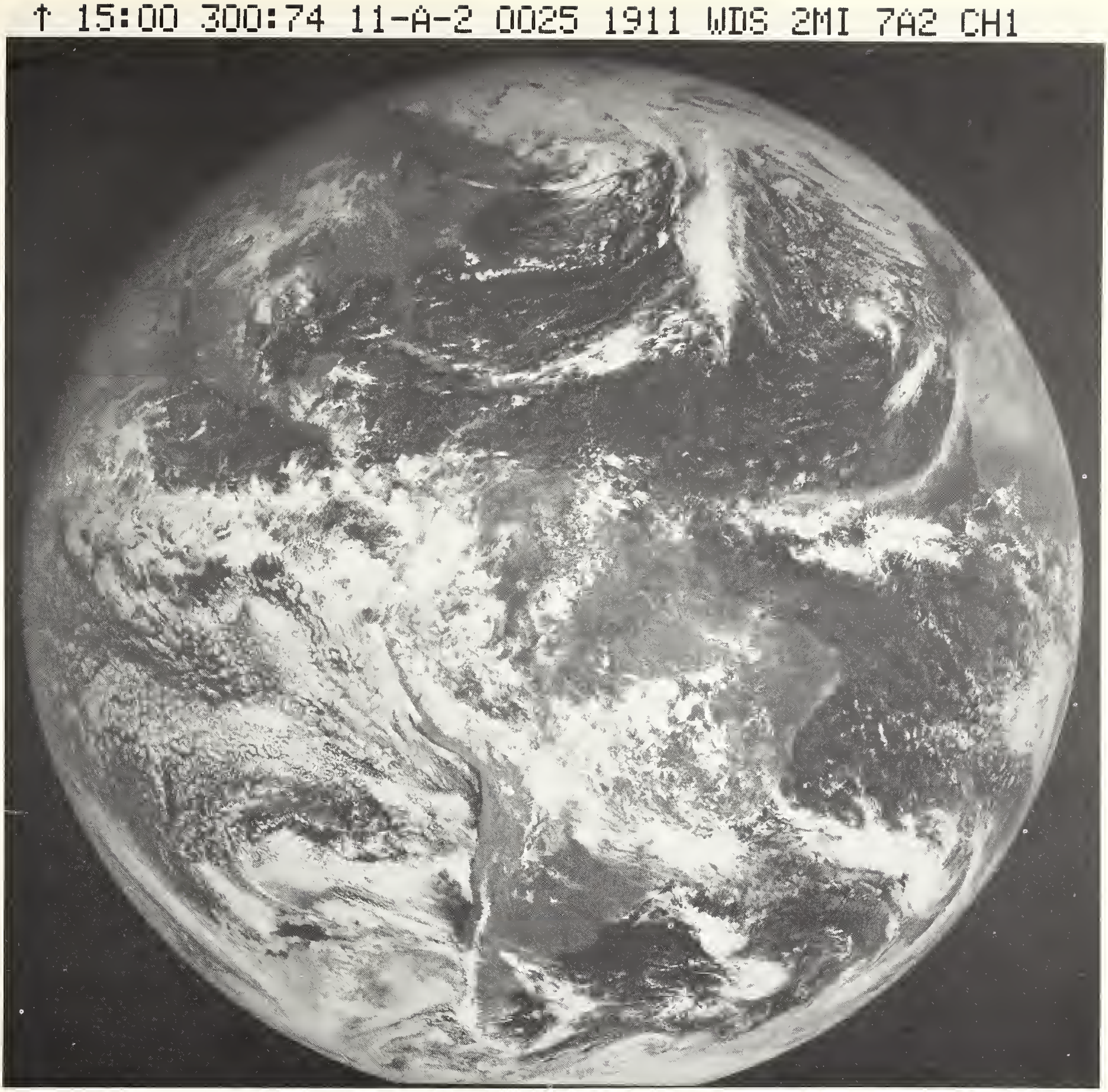

Figure 12-2.--SMS-1 2- x 2-mile resolution visible picture, 1500Z, October 28, 1974

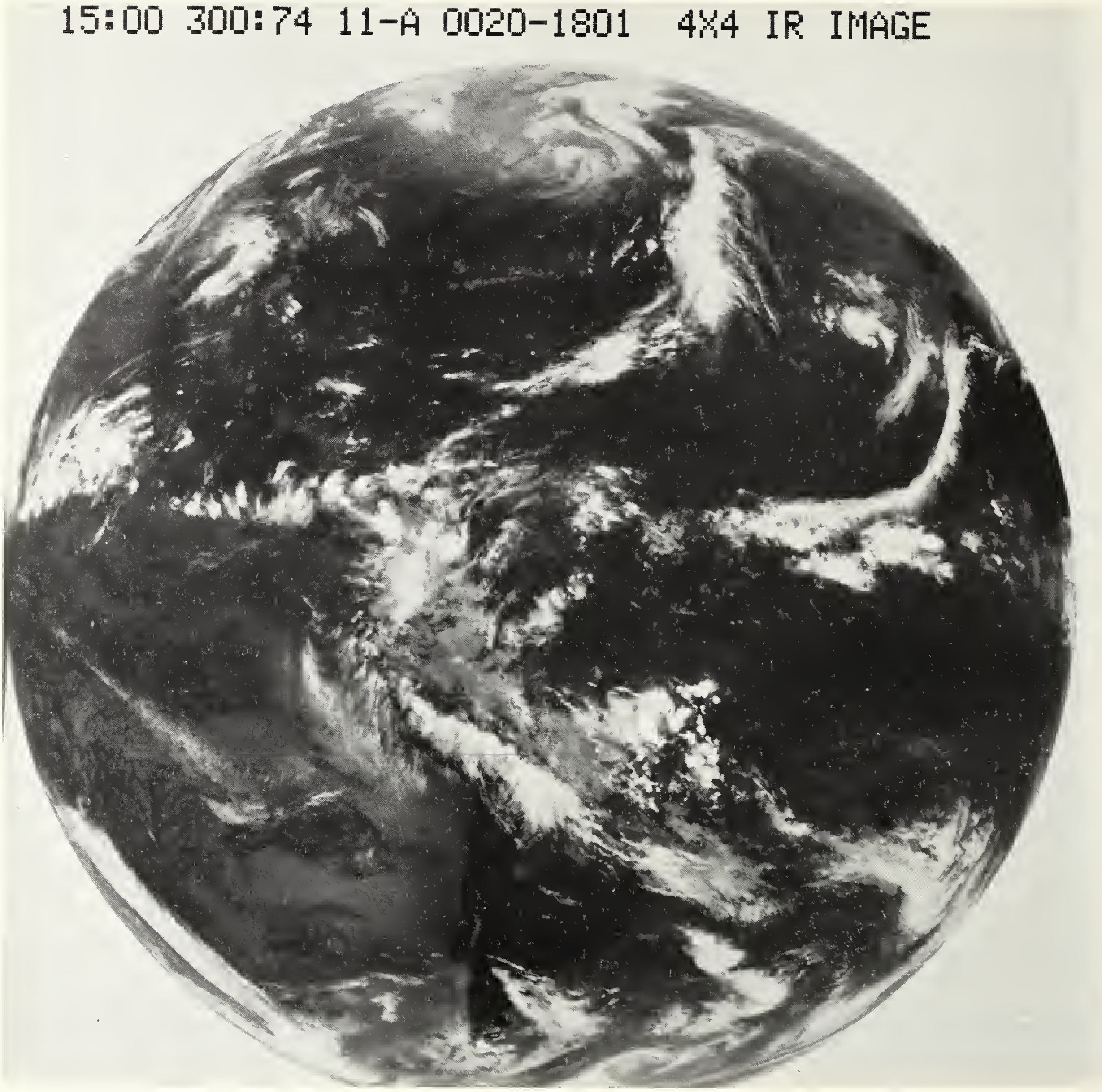

Figure 12-3.--SMS-1 2- x 4-mile resolution infrared picture, 1500Z, October 28, 1974

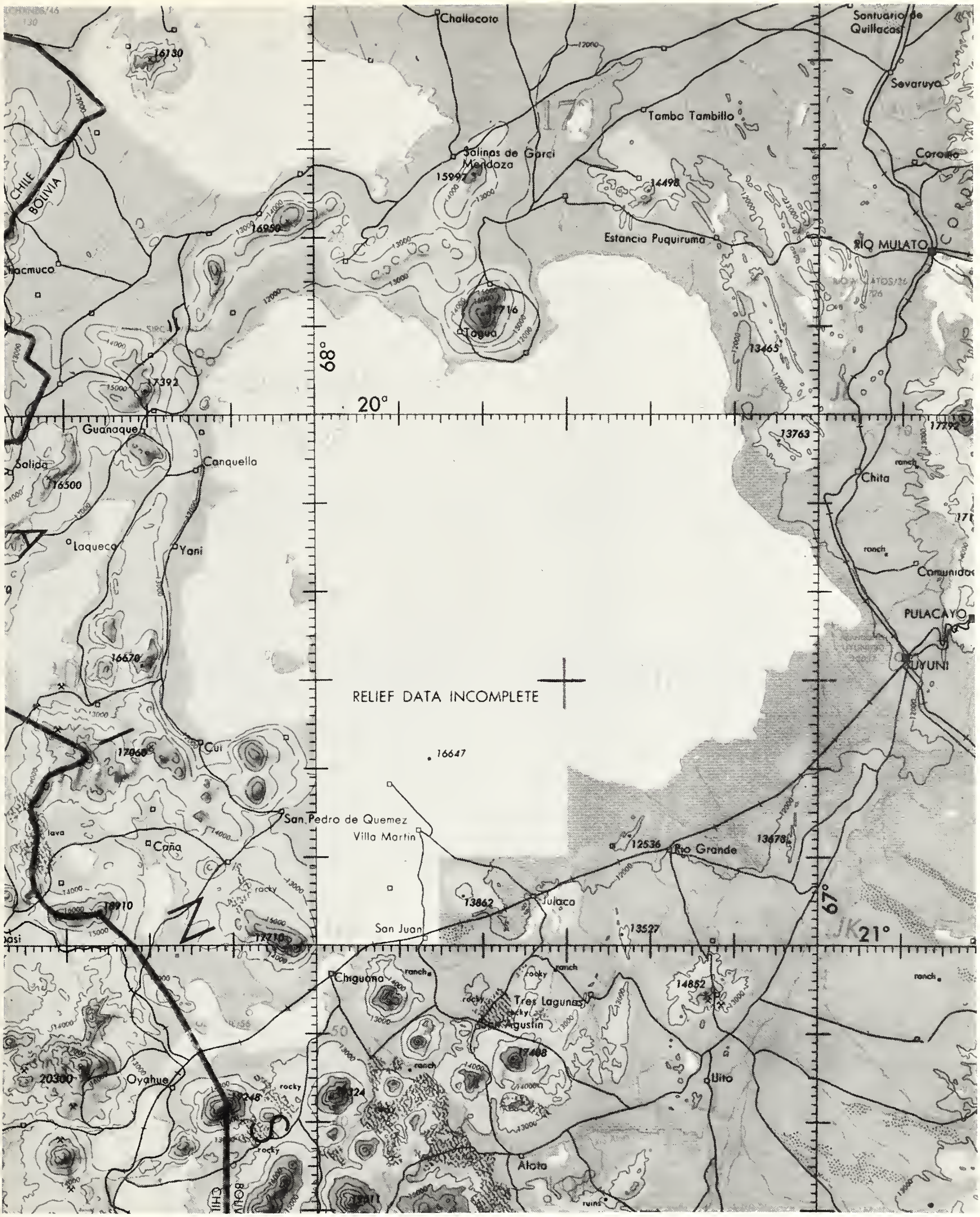

Figure 12-4.--Detailed map of Solar De Uyuni salt flats in Bolivia. The cross, +, at 20.5°S and 67.5°W is the position chosen for registration purposes.

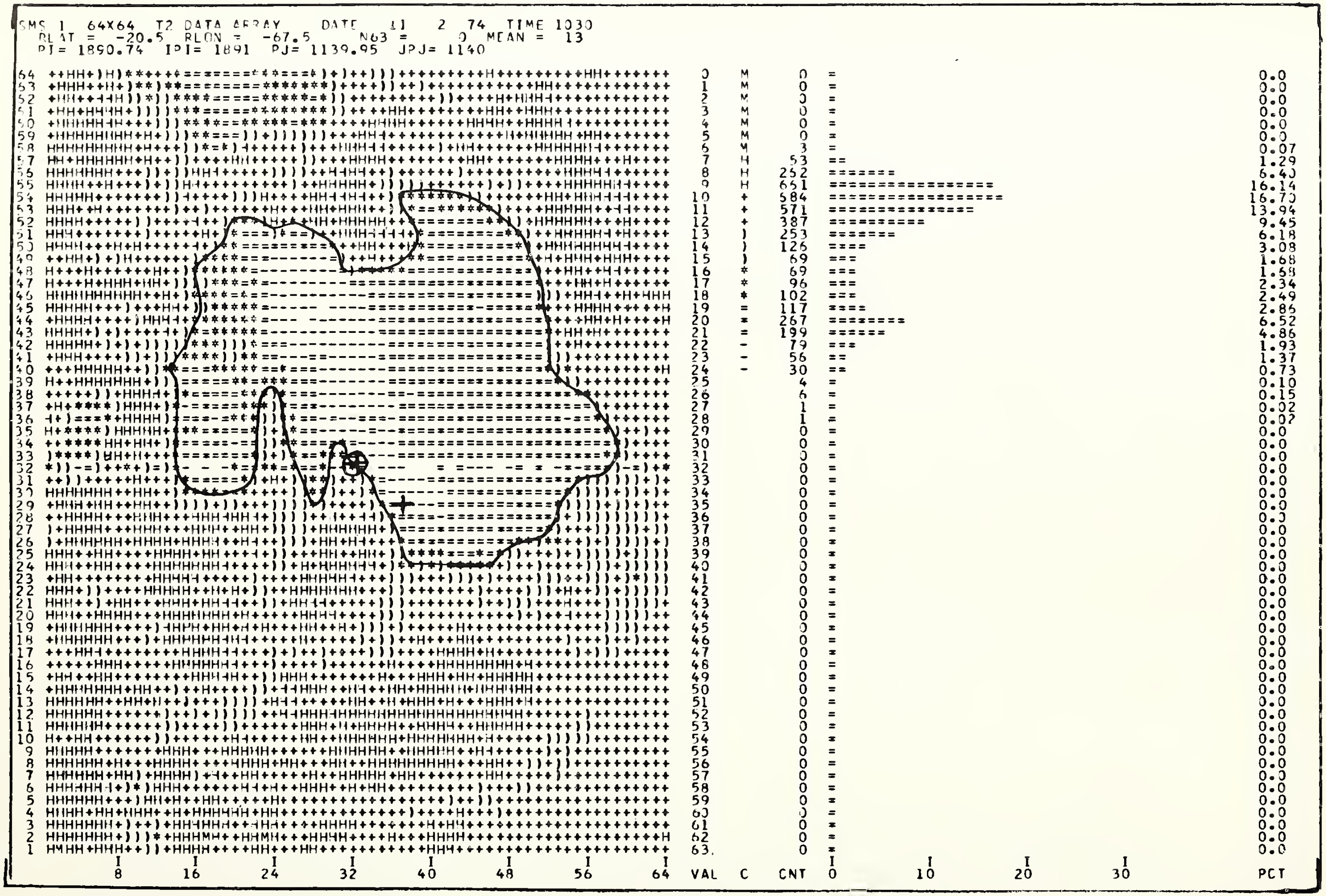

Figure 12-5.--Gray scale depiction, using alphanumeric characters, of the Solar De Uyuni as observed by SMS-1 at 1030Z on November 2, 1974. The cross, "+", at 37, 29 which should have been located at 32, 32 (circled cross, ⊕) corresponds to the position of the cross in figure 12-4. The difference between the array center (32, 32, ⊕) and the apparent position (37, 29, +) represents the geographical error.

PRIMARY FREQUENCY DIST, PEAK AT (-1, 0)

	-16	-15	-14	-13	-12	-11	-10	-9	-8	-7	-6	-5	-4	-3	-2	-1	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
14	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
13	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0
12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0	2	0	1	0	0	3	3	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1	0	0	0	0	0	0	0	0	0	0	0	0	4	0	2	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	3	3	2	30	2	0	2	2	2	1	0	0	0	0	0	0	0	0	0	0	0
-1	0	0	0	0	0	0	0	0	0	0	2	0	0	2	1	7	0	0	3	3	2	2	2	1	0	1	0	0	0	0	0	0	0
-2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	2	2	2	2	1	0	0	0	0	0	0	0
-3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	2	0	0	0	0	0	0	0	0
-4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0
-5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
-6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
-7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	1	0	0	0	0	0	0	0	0	0	1	1	1
-8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
-9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
-10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
-11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
-12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
-13	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
-14	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
-15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
-16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Figure 12-6.--Frequency distribution of the lag value positions of the cross-correlation peak values for landmark registration of the 1030 and 1100 GMT pictures of SMS-1 data on November 2, 1974. The peak occurs at -1,0.

SECONDARY FREQ DIST

16	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
15	0	0	0	0	1	1	0	0	1	0	0	0	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
14	0	1	0	0	0	1	0	0	1	0	1	1	0	0	0	1	0	1	1	1	0	0	0	0	1	0	0	0	0	0	0	0	0
13	0	0	0	0	0	1	1	2	0	1	2	2	0	1	1	1	1	1	0	1	1	0	1	0	0	0	0	1	1	1	1	0	0
12	0	1	2	1	0	0	0	1	1	1	2	0	2	0	0	1	0	0	2	2	1	0	1	1	1	1	0	0	1	1	2	1	0
11	0	0	1	1	1	1	0	1	0	1	2	1	0	1	1	0	0	0	1	1	1	0	0	1	1	0	0	0	0	0	2	0	0
10	0	0	2	1	2	2	0	0	0	1	2	1	0	1	1	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
9	0	1	1	2	1	2	0	0	0	1	0	1	0	1	0	0	0	0	0	1	0	0	0	0	0	1	1	0	0	0	0	1	0
8	1	1	0	1	1	1	1	0	0	0	1	2	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7	0	0	0	0	1	2	0	0	0	0	0	1	1	1	0	0	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
6	0	0	0	1	0	0	0	1	1	0	0	1	2	1	0	0	0	0	0	0	0	0	0	1	1	0	0	0	1	0	0	1	0
5	0	1	0	0	0	0	0	1	2	2	1	1	1	0	0	0	0	1	0	0	0	1	0	0	0	0	0	2	2	1	3	3	1
4	1	1	2	1	0	0	0	1	2	1	1	0	1	1	3	1	0	0	0	0	1	1	1	1	2	1	2	2	2	1	3	2	1
3	0	1	1	0	0	0	0	0	0	0	0	0	1	2	1	0	0	0	0	0	0	1	0	1	1	1	3	1	3	1	0	1	1
2	0	1	2	2	1	1	1	2	0	0	0	0	0	2	3	1	0	0	0	0	1	0	1	2	1	1	3	2	2	1	0	0	0
1	1	1	1	2	2	1	2	2	0	1	0	0	0	0	1	1	0	0	1	1	2	1	2	1	1	0	2	2	1	0	0	0	0
0	2	4	3	2	1	2	1	1	0	1	0	0	0	9	3	3	1	0	1	0	3	2	4	1	1	0	0	0	0	0	1	0	1
-1	1	1	1	0	1	2	1	2	0	1	0	0	1	0	1	0	3	2	0	1	2	3	3	0	2	2	0	0	0	0	0	0	0
-2	0	1	1	1	1	0	0	1	0	0	0	0	0	0	1	0	0	2	0	1	0	0	0	1	2	2	1	0	0	1	0	1	1
-3	0	0	0	0	0	0	0	0	0	0	0	0	0	1	2	1	2	1	0	0	0	0	0	1	1	3	1	1	1	1	1	0	0
-4	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	1	0	0	0	0	0	1	2	1	1	0	1	1	2	1	2	1
-5	0	0	0	0	1	1	0	0	0	0	1	1	1	1	2	0	1	0	1	0	1	0	0	0	1	0	0	0	0	1	2	1	0
-6	0	0	0	0	0	1	0	0	1	0	1	0	0	0	2	1	1	0	0	1	1	0	0	1	1	0	0	0	0	0	0	1	0
-7	0	0	0	0	0	0	0	1	2	0	0	0	0	0	0	1	2	0	0	0	1	1	0	0	0	0	1	0	0	0	0	0	0
-8	0	0	0	0	0	0	1	1	0	0	0	0	0	0	1	0	1	2	2	1	2	1	0	0	0	0	0	1	1	0	0	0	0
-9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	2	1	1	0	2	2	1	0	0	0	0	1	1	1	0	0
-10	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	1	1	0	0	0	1	1	0	1	0	0	0	0	0	1	0	0
-11	1	1	2	0	0	0	1	0	0	0	0	0	1	0	0	0	1	2	0	0	0	2	1	0	0	1	0	0	1	0	0	0	0
-12	1	2	1	0	1	0	2	1	0	0	1	2	1	0	0	0	1	3	1	0	0	1	1	0	0	0	1	0	1	0	1	2	0
-13	0	0	1	1	1	1	0	1	0	0	1	3	2	0	0	0	0	2	3	0	0	2	2	2	1	0	0	1	0	0	1	2	1
-14	0	0	0	0	0	1	1	0	0	0	1	2	0	1	0	0	0	0	2	1	0	1	2	1	1	0	0	0	1	0	0	1	0
-15	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1	1	0	1	0	0	0	0	0	0	0	0	1	1	1
-16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0	1	1	1	0
	-16	-15	-14	-13	-12	-11	-10	-9	-8	-7	-6	-5	-4	-3	-2	-1	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16

Figure 12-7.--Frequency distribution of the lag value positions of secondary maxima corresponding to figure 12-6. The dispersion of apparent motion is obvious. There is only a minor influence in the 3 x 3 area around the point -1,0.

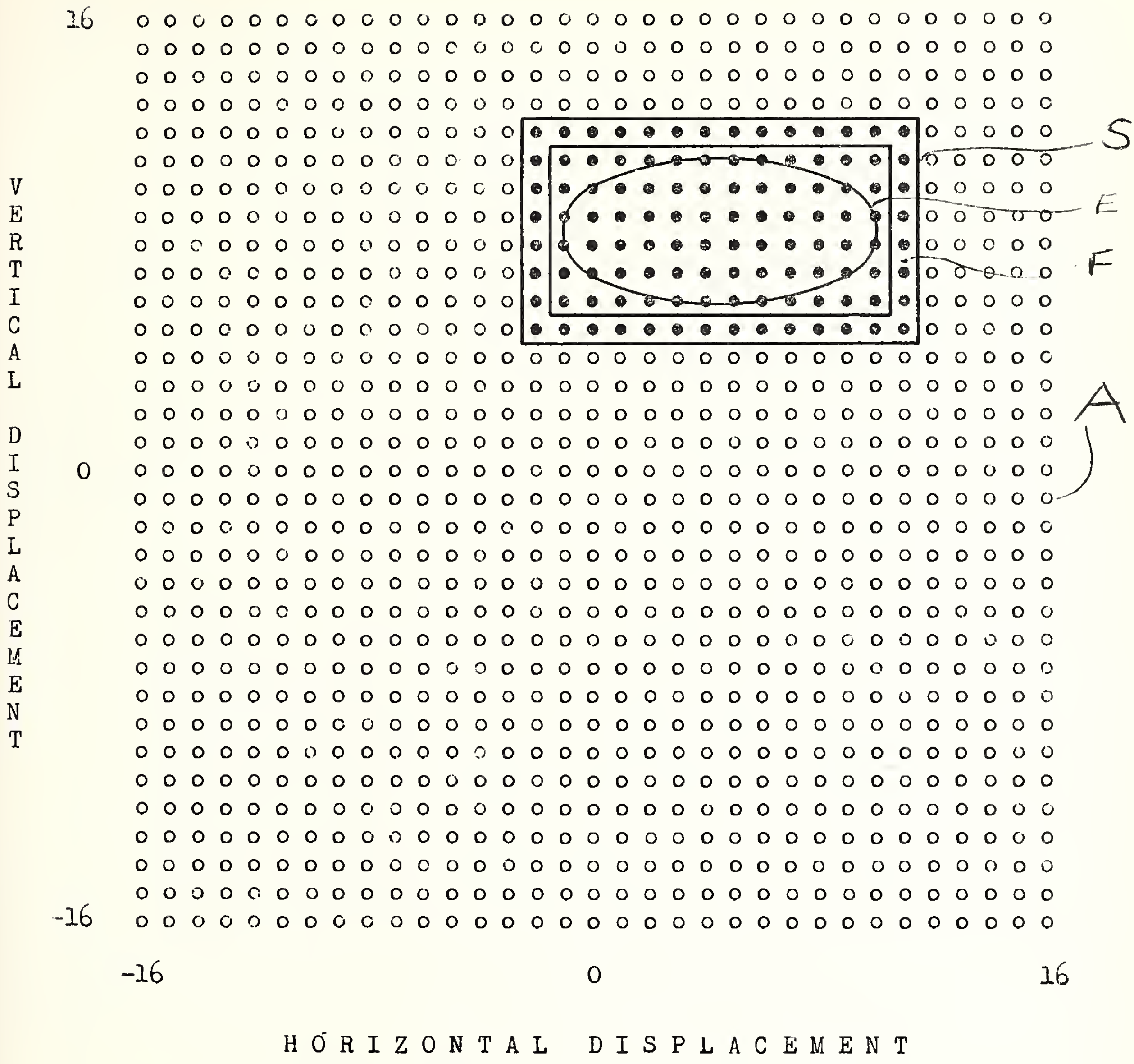

Figure 12-8.--Ellipse E surrounded by frame F in subarray of 33 x 33 array of correlations. (Solid dots indicate lag values for which correlations are computed during preliminary search.)

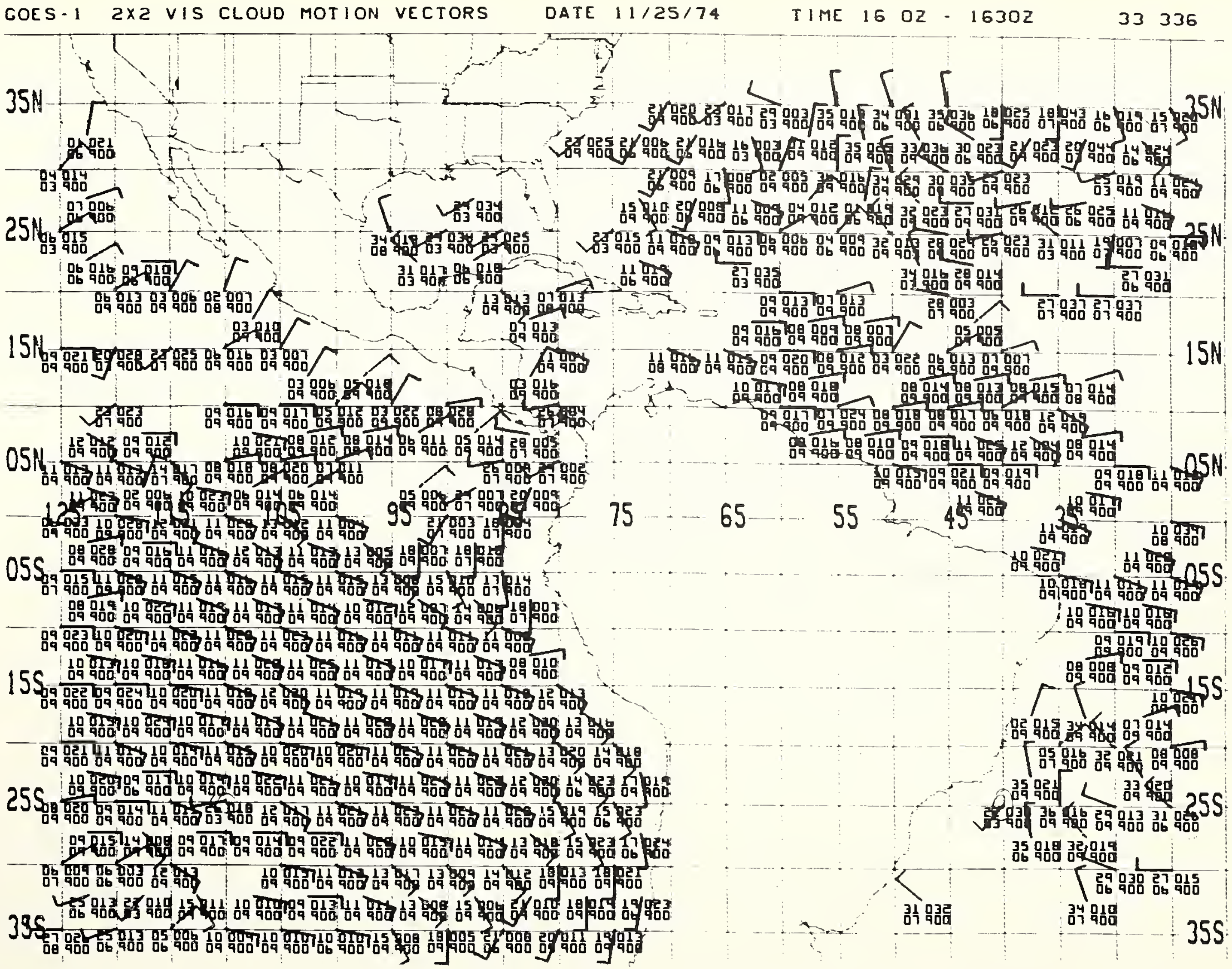

Figure 12-8.--Mapped vector field in the GOES-1 area for picture pair times 1600-1630 GMT on November 25, 1974 as presented to the meteorologist/analyst. The barb indicates the wind direction (36 point compass). The direction in tens of degrees and the speed in knots are printed immediately below each vector. The quality index (tens of percent) and the millibar level (900) are printed immediately below direction and speed.

13

THE GOES WIND OPERATION

M. T. Young

INTRODUCTION

The three immediately preceding segments of this combined report describe in some detail the processes and activities by which VISSR picture sequences are transformed into time-lapse loop movies, the MMIPS facility for the extraction and presentation of numeric data for use in assigning altitude information to derived wind vectors, and an automated procedure for the computer extraction of low-level wind vector estimates from picture pairs. The Wind Section operational procedures used for combining hand-derived and computer-derived wind estimates into an edited output product are described herein. Particular attention is given to the hand production system and the final editing step.

FILM LOOP TECHNIQUES

Data used in the time-lapse movie loop wind production are the VISSR 8-km IR and 4-km VIS image sequences. Response adjustments in the film generation equipment enhance the IR image response at the warm (290K) end. The resulting increased contrast permits the human analyst to more easily discriminate between low level clouds and underlying sea surface or terrain features. A typical winds loop, whether VIS or IR, includes six images taken over a 2 1/2 hour time span.

The loop, when run continuously through a projector, displayw cloud motions over and over; this permits a systematic analysis of the cloud motion field. To define the cloud displacements more accurately, the first and last frames in the loop are repeated 20 times, while each internal frame is displayed twice. The end result is a film sequence that shows the initial cloud field, holds it motionless for a few seconds, displays the cloud motions during the next five frames, and then holds the final cloud field motionless, again for a few seconds, before the sequence repeats. By "holding" the first and last views in the sequence, cloud motion vectors can be easily identified and their displacements accurately measured.

CLOUD MOTION ANALYSIS

Meteorologists of the NESS Satellite Winds Section analyze film loops three times daily, at 10Z, 16Z, and 22Z, and the winds data derived are used in the corresponding 12Z, 18Z, and 00Z weather analyses. Film loops are normally prepared for wind vector analysis for the North and South Atlantic oceans (including South Africa) and the North and South Pacific oceans. Emphasis is placed on these areas because of the sparsity of other meteorological observations.

An overhead, closed-loop moving projector is used to display the film loop on a paper worksheet placed on a plotting board. The analyst measures cloud motions by making a pencil mark at the initial position of the cloud element and a second pencil mark at the final cloud position. He then indicates the direction of motion by drawing an arrow connecting the two points.

In the infrared mode the analyst has little difficulty distinguishing between low, middle, and high clouds used as motion tracers. IR imagery is presented in approximately 18 shades of gray with warm (300K) temperatures shown as black and cold (220K) as white. Thus, the sea surface appears dark gray, low clouds medium gray, and middle and high clouds light gray and white respectively. (This display igzores the variable emissivity of clouds, which is discussed below.)

Recognition of the major synoptic features, especially in the visible mode, is also essential for identification and evaluation of associated cloud patterns. Features such as cyclonic vorticies, cold fronts, tropical disturbances, jet streams, and subtropical high pressure systems are readily identifiable in both IR and visible modes. Clouds of suppressed vertical development, such as stratocumulus, occurring under the influence of a well developed tropical high pressure system make excellent low level tracers. Cirrus clouds, often associated with jet streams, are readily identified by their gray shade (IR) and rapid motion. These clouds are often used as tracers of high level wind flow. The analyst avoids tracking clouds that appear to change in size, shape, or brightness during the film sequence; clouds at several altitudes are also avoided in the presence of shearing flow unless good tracers are clearly separable.

Once cloud tracers have been selected and the incremental motions marked on the worksheet, the analyst next derives a blackbody radiative temperature for each using the Man-Machine Interactive Processing System (MMIPS).

USING MMIPS IN CLOUD HEIGHT DETERMINATION

The procedures to input VISSR data into the MMIPS are divided into two modes: initialization and processing. The entire procedure is under the direction of a resident software package called DOSS (Day-One SMS System).

In the initialization mode, SMS IR data are ingested and further prepared by a set of five fixed sequential commands. All commands are entered by the Winds Section meteorologist on the keyboard associated with the digital CRT. Incoming data undergo two preprocessing conversions before being transferred onto the MMIPS mass storage area (disk pack). The SMS 8- by 4-km (overlapped) samples are converted to 8- by 8-km resolution by averaging contiguous pairs of data samples along each scan line. This results in an earth image consisting of up to 1,821 scan lines with up to 1,911 samples in each line. Samples are also converted from encoded values to temperature (Kelvin) values via a look-up table in DOSS. Once the converted data samples are transferred to the MMIPS mass storage area, they are then automatically displayed as a full image on the video CRT. The meteorologist must select a 1400 x 1400 sample set from the original image to be further divided into nine sectors. In the nine-sector mode, image displays are in full 8- by 8-km MMIPS resolution. The selection of a sector of the original earth image is accomplished by moving a target selector spot with a ball device. A target spot and nine-square grid overlay, centered about the target, are superimposed over the earth image. The grid thus defines the boundaries of the nine sectors.

Once this selection of sectors is made, a prestored gray scale, automatically provided within the initialization mode, converts the Kelvin temperatures to 4-bit intensity values (16 shades of gray). The final step in the initialization mode is to write the desired sectors onto the video disk. Six video storage areas are available for display on the CRT. The meteorologist must assign at least one sector and may assign all six sectors. The sectors are transferred from the mass storage disk and written onto the video disk. At this time, the meterologist can immediately display any of the six sectors on the CRT. Once initialization is completed, the meteorologist is ready for the processing mode and the derivation of cloud temperatures.

In the processing mode, MMIPS is used interactively to display representative cloud-top temperatures. The analyst makes decisions as to emissivity and so relates cloud temperatures to equivalent blackbody values. The blackbody temperature of a cloud equals the actual cloud temperature only if the cloud is sufficiently dense to shield the satellite sensor from radiation below the cloud. Since many cloud motion tracers are not sufficiently dense, the total radiation sensed by the satellite represents the sum of cloud tracer radiance and that from the underlying sea surface or lower-level clouds. This is expressed by:

$$B_T = B_c + B_S \tag{1}$$

where: B_T = radiance at satellite,

B_c = radiance from cloud, and

B_s = radiance from surface.

The radiance received from a cloud tracer is a function of its temperature and its emissivity. Emissivity (E) can be defined simply as the radiating efficiency of a black body. In this case, E is primarily a function of the opacity of the cloud tracer. Therefore:

$$B_T = B_c E + B_s(1 - E)$$

where: E = emissivity of cloud

$(1-E)$ = transmissivity of atmosphere from B_s through B_c.

Solving for B_c we get:

$$B_c = [B_T - B_s(1 - E)]/E \quad (2)$$

Since both cloud tracer temperature (B_T) and surface temperature (B_s) are measurable quantities, cloud emissivity (E) becomes an important but subjective quantity.

To reduce uncertainty in emissivity estimates, the analyst must choose as tracers the densest and, therefore, the most emissive clouds. This is accomplished by thorough examination of gray scale values in both visible and IR film imagery. Cloud tracers which appear white in both modes will be of sufficient height and opacity for cloud temperature analysis. Thus, the analyst has limited his cloud emissivity estimates to values of between 0.75 and unity.

Once the analyst has identified the most emissive cloud tracers, he must then determine the temperatures of those tracers. This is accomplished by using the processing mode of MMIPS. After centering the cloud tracer within a target cursor square, 17 lines by 17 elements in extent (68 x 68 n.mi.), the analyst commands the DOSS to display a 17 x 17 array of temperature values on the companion digital CRT. The analyst must determine the coldest, i.e. the most emissive, part of the cloud. He commands the DOSS to calculate and display a standard frequency distribution of temperature values. He chooses for his temperature value the coldest cluster of values in the distribution. Cold temperatures with a cumulative frequency of two or less are dismissed as noise (possibly overshooting cumulonimbus towers). If the analyst has previously determined that the cloud tracer under inspection is opaque, the derived temperature is accepted as the tracer temperature. However, if the analyst has estimated an emissivity of less than unity he must then calculate an underlying surface temperature and derive tracer temperature through the algorithm expressed by eq (2).

By careful inspection of the movie loops, the analyst determines the nature of the underlying surface, i.e. sea surface or low-level cloud. He then moves the cursor to that surface and commands DOSS to display a 17 x 17 temperature array and standard frequency distribution. He chooses the most representative surface temperature and thus has derived all the necessary input parameters for use in the tracer temperature derivation algorithm.

The three parameters--cloud temperature (T_c), surface temperature (T_s), and emissivity (E)--are now known. The analyst then enters the parameters (via the digital CRT keyboard) into the tracer temperature derivation algorithm and commands DOSS to solve the equation. The equation is solved for three emissivity values, i.e., 0.75, 0.85, and 0.95. The answers are displayed on the digital CRT, and the analyst accepts the one that corresponds to his original emissivity estimate. A typical numeric display is shown in figure 13-1.

DIGITIZER OPERATION

The translation of cloud image coordinates into cloud motion vectors and the translation of MMIPS-derived temperatures into specific pressure altitudes are accomplished most efficiently by computer. To be acceptable as computer input, cloud displacements and temperatures must be formatted numerically. This is done by the use of the Bendix "Datagrid" Digitizer (fig. 13-2). The digitizer is a two-dimensional coordinate measuring system that translates the endpoints marked on the worksheet into X,Y coordinate components. Coupled with an output device, in this case an IBM 029 Card Punch, it supplies the properly formatted numerical data for computation.

The Datagrid Digitizer consists of two parts, a plotting board and cursor, and an electronic counter. The plotting board is a Formica-covered table with a 30- by 36-inch working area. A rectangular array of electronic conductors is imbedded in the table. The cursor is a clear plastic disk containing cross hairs and a small circle for centering the point to be digitized. A coil is mounted in the body of the cursor. As the cursor is moved, X,Y coordinate signals are generated in the imbedded grid through inductive coupling. These signals are interpreted digitally with accuracy to 0.001 in.

The digitizer and card punch are used to transcribe image coordinates and geographical reference coordinates onto data cards as follows: The worksheet marked with the start and end points of the motion vectors and the MMIPS-derived temperatures is placed on the plotting board. The cursor is centered over nine-preselected geographic grid points distributed symmetrically about the film-loop field of view. A button is pushed to record the X,Y coordinates on punch cards (fig. 13-3). Thus, the geographic grid of the movie is referenced to the X,Y coordinate field. The cursor is then placed over the start and end points of the motion vectors.

At present, the MMIPS-derived temperatures corresponding to the individual cloud motion vectors are manually recorded on the punch cards. After transcribing the temperatures, the X,Y coordinates of the start and end points are recorded. The digitized data thus generated are acceptable for computer analysis. A remote job-processing terminal is available in the Winds Section and provides access to the large-scale IBM 360/195 system. Once the input data cards have been loaded, calculation of wind vector estimates can begin. Since the loop movie image scene is projected onto the worksheet with considerable enlargement, the X,Y coordinates obtained from it do not limit the precision of the computation. For example, the angular increment at the satellite represented by 0.001 inch on the digitizer board corresponds to approximately one-fifteenth of the stepping angle between successive scan lines of the satellite camera.

VECTOR CALCULATION AND HEIGHT DETERMINATION

A computer program, LUPWND, is used to translate the raw input data in digitized X,Y coordinate format to earth located, height labeled, cloud motion (wind) vectors. Some inherent problems are encountered in the translation of cloud motions into earth located vectors. One of the major difficulties is the angular distortion resulting from the flat plane camera view of the spherical earth. Apparent cloud motions are true directly beneath the camera but become distorted toward the horizon. This distortion is removed by translating the plane rectangular coordinate system of the film loop image to the spherical earth.

Since the satellite spin axis is not alined precisely with orbit normal, the resulting roll-and-yaw interchange creates rotational and "tilt" differences between successive images. With a slightly inclined orbit, the subsatellite position also meanders during the loop picture sequence. The LUPWND program deals with the resulting earth location differences by using appropriate orbit and attitude information corresponding to the time at each vector end-point measurement. A technical description of LUPWND is provided elsewhere (Young, Doolittle, and Mace, 1972).

Height (pressure altitude) determination is accomplished through access to the National Meterological Center data base on the 360/195 system. Once LUPWND has calculated an accurate vector earth location, the MMIPS-derived temperature is referenced to the latest analyzed vertical temperature profile at that location. The temperatures match at one pressure altitude and this reference, rounded off to the nearest 10 mb, becomes the vertical location of the wind vector.

This method of defining vertical location is an enormous improvement over the more subjective, manual estimates of pressure altitude. Previously, with ATS-1 and ATS-3 visible imagery, cloud heights were assigned to three specific levels--850 mb for low-level cumulus clouds, 500 mb for middle-level clouds, and 300 mb for high-level cirrus tracers. These heights were assigned as a function of the analyst's subjective judgment (Young, Doolittle, and Mace, 1972). The use of MMIPS-derived temperatures, and linkage to the NMC data base provide for more accurate and, therefore, more useful wind data.

MANUAL EDITING AND DELIVERY

Low-level (900 mb) vectors are operationally produced by the "Picture Pair" method as discussed by Novak in paper 12 of this memorandum. The Satellite Winds Section is concerned with the output of this product. For editing purposes the picture pair vectors are produced in graphic form. (See paper 12, this memorandum.)

Three times daily, an unedited vector-pair analysis is presented to the analyst. He transcribes the latest surface pressure field, frontal systems, and high level cloud patterns onto the graphic vector display (fig. 13-4). To be acceptable, each vector must be in approximate agreement with the indicated geostrophic flow derived from the previous 6-hourly surface analysis. The analyst has little trouble in identifying vectors that depart markedly from the analysis. Since each picture-pair vector carries a unique identifier, those rejected are readily purged from the computer disk file. The anlyst then uses the movie loop process to generate gap-filling replacement vectors.

It is the responsibility of the Satellite Winds Section to edit and combine picture-pair and MMIPS-derived vectors for all possible upper air levels and to delivery them as operational products to the NMC and other worldwide users. Once the complete set has been produced, it is moved to a disk product area. The vectors are then accessed by NMC for use as input for its Global Analysis Model. The product vectors are also referenced by an analyst-selected computer program which reformats the information into an observational code form and initiates a teletype transmission to all worldwide users.

VERIFICATION

Daily comparisons are made between the wind vector data derived by the described method and the conventional balloon sounding data. The primary purpose is to provide the analyst with immediate feedback on the quality of his product. A secondary purpose is to provide a long-term data base for statistical comparison of the vector deviations calculated by comparing the picture-pair and loop methods.

The 12Z satellite-derived wind vectors are placed on a temporary 360/195 disk file. By activating a computer program, 12Z rawinsonde data from upper air stations in the Northern Hemisphere are retrieved from the NMC data base and compared to the MMIPS-derived vectors. Satellite vectors that fall in an elliptical search area about upper air stations are selected for verification, printed out, and stored on 360/195 disk space. The major axis of the elliptical search area is alined along the flow of the MMIPS vector. The size of the search area varies between one and two degrees of latitude along the minor axis and two and three degrees along the major axis. For vectors with velocities greater than 40 kts, the larger search area is used. When a location match is found, the computer plots an upper air temperature/pressure/wind profile of the upper air sounding. The MMIPS-derived vector is checked against the sounding wind at the derived pressure level. Both wind values are recorded and the computer then searches for a better wind vector match at other pressure levels along the sounding profile. This pressure level (level of best fit) is also recorded.

Cases are noted when unreasonable wind vector deviations occur at the derived pressure level or when large vertical differences occur between the MMIPS-derived pressure level and the level of best fit.

On such occasions, the analyst may wish to reexamine the particular cloud tracer on both the movie loop and the MMIPS to determine the probable cause of the error.

All comparisons are recorded on computer disk. Periodically, the vector deviations between MMIPS-derived vectors and direct sounding observation are totaled and cumulative frequency distributions are derived. These distributions may indicate to the analyst systematic errors which are correctable. For example, frequency distributions may indicate that, for thin cirrus, the MMIPS-derived temperatures are consistently warmer than those corresponding to the level of best fit. If so, the analyst may revise techniques for deriving thin cirrus temperatures.

At present, wind estimates derived from cloud motions contain empirical elements. Apart from the basic assumption that clouds provide true air flow tracers, the estimation of cloud emissivity is perhaps the most empirical. Because the ultimate value of the satellite-derived wind estimates lies in their departures from analyses made without such information, the editing process must also contain a judgmental subjectivity element. Within these empirical constraints, we continue to strive for high precision in vector measurement and calculation, and through close product monitoring, we expect to minimize artificial biases.

291	289	283	277	283	290	292	293	293	293	293	293	293	293	293	293	293
290	283	270	274	288	292	292	293	293	293	293	292	293	293	293	293	293
282	281	280	287	291	292	292	291	290	291	292	292	293	293	292	293	293
279	288	291	291	292	289	283	283	284	284	286	291	292	292	293	292	293
274	287	292	292	289	278	266	262	270	275	276	280	285	289	292	293	293
274	283	288	287	279	265	261	253	249	249	249	257	270	282	288	290	291
289	287	284	277	269	259	252	247	245	245	244	242	253	270	281	287	291
291	289	286	280	270	263	256	249	246	245	244	243	249	261	274	284	288
289	285	279	274	266	261	255	249	244	239	243	246	255	266	278	282	285
285	284	281	271	262	254	249	246	241	236	242	246	254	269	284	287	287
274	280	287	285	277	261	251	245	240	235	243	247	255	268	279	285	288
265	282	288	287	278	264	255	250	248	244	242	244	255	268	273	288	292
271	285	288	285	278	274	271	259	250	245	244	249	262	271	280	288	291
279	285	284	282	276	278	271	257	251	253	254	262	269	265	270	283	289
275	282	285	284	283	279	268	258	261	270	275	279	276	265	260	271	286
267	281	289	290	291	287	279	274	280	282	279	280	279	266	256	266	283
274	284	289	291	292	292	287	282	285	285	276	275	278	264	254	265	282

Figure 13-1.--Sample 17 x 17 temperature array in degrees kelvin. (Contours are added every 10°K.) A single cirrus cloud tracer overlying the sea surface is depicted. Temperature values of 244 for cloud top and 292 for sea surface are chosen as input parameters to tracer temperature algorithm.

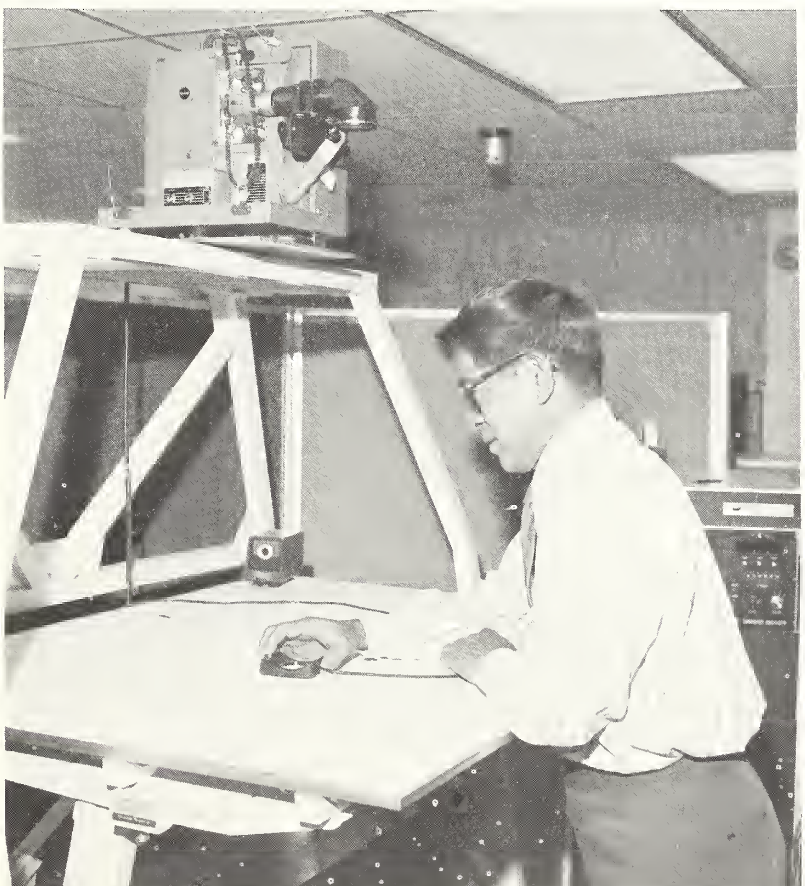

Figure 13-2.--The vector end point extraction station consists of the loop movie projector and the Bendix "Datagrid" Digitizer. Not shown is the attached IBM 029 card punch which provides output.

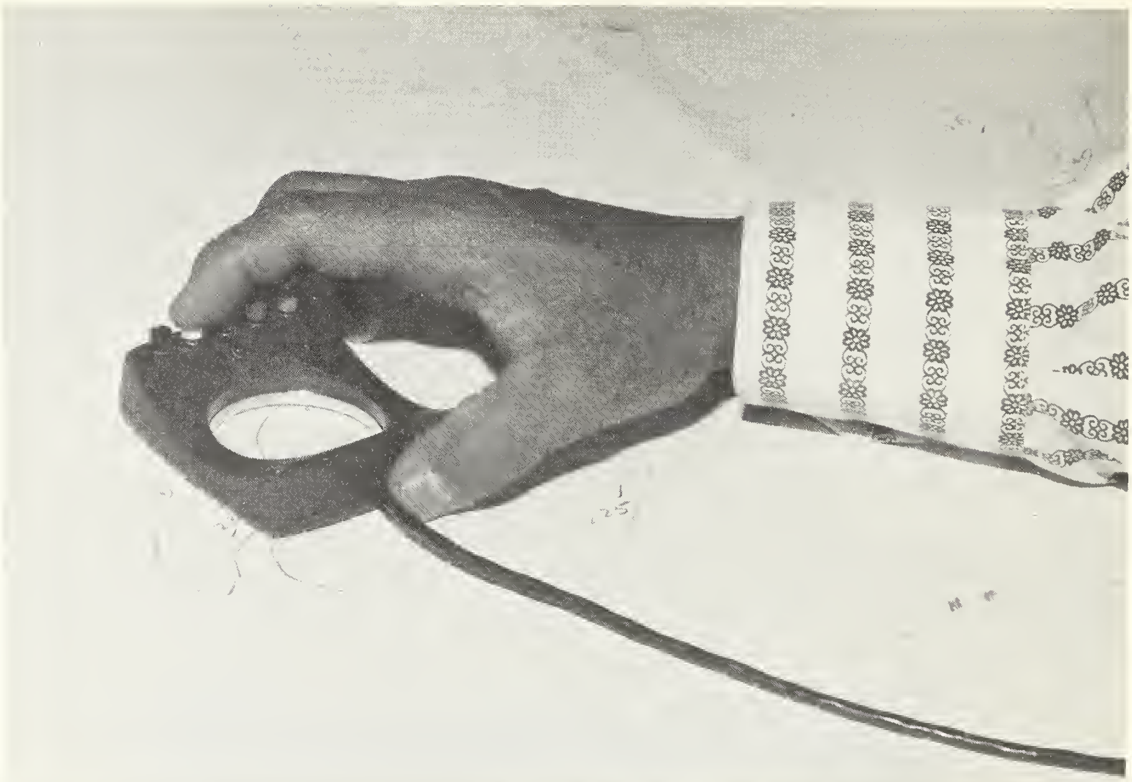

Figure 13-3.--Control buttons on the "Datagrid" cursor provide for activation of the card punch.

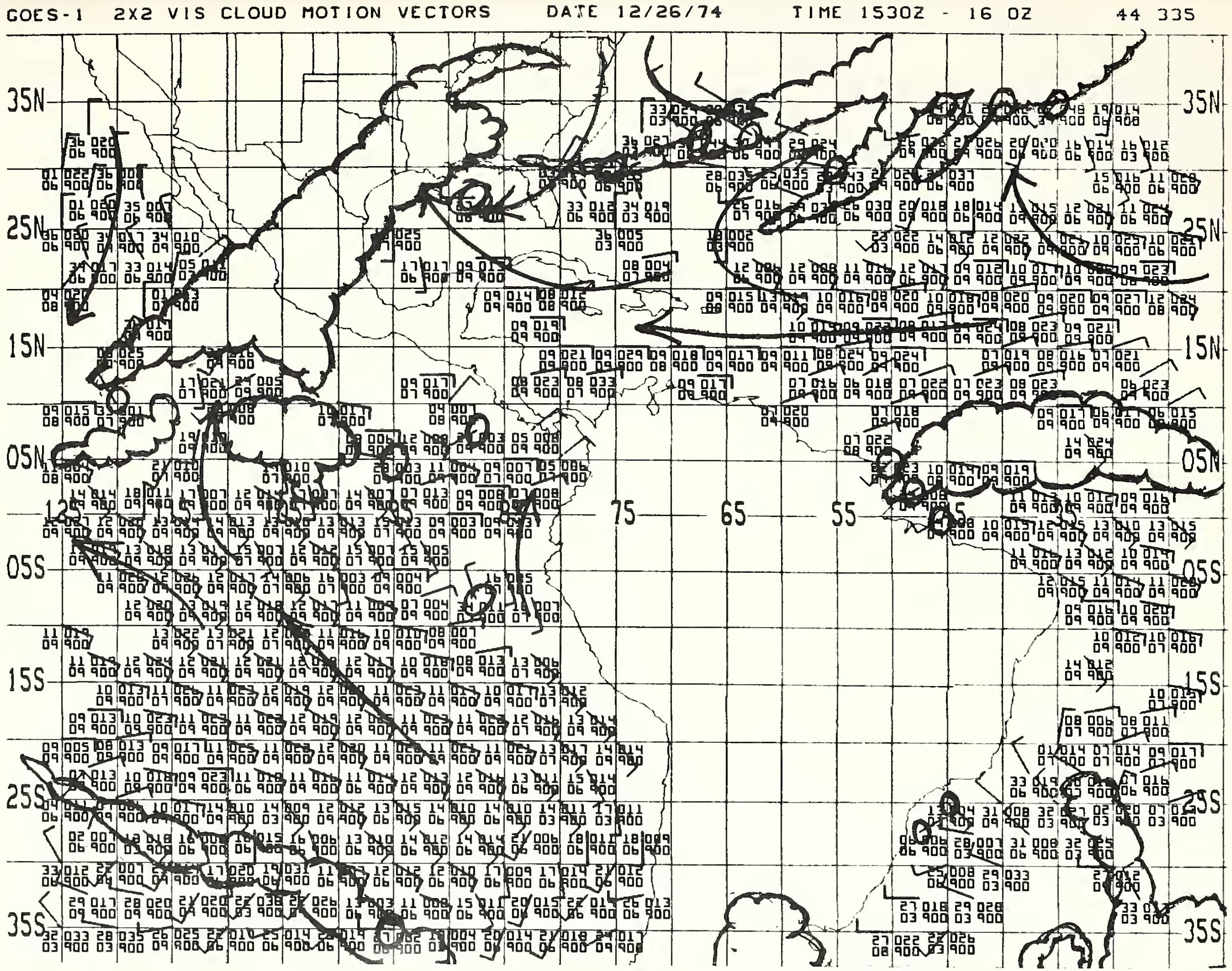

Figure 13-4.--Edit plot showing picture pair vectors and transcribed cloud patterns and synoptic flow indicators.

14

MANUAL ANALYSIS OF VISSR DATA

F. Bittner and L. Mace

INTRODUCTION

The mission of the Analysis and Evaluation Branch of the NESS is to interpret data received from operational environmental satellites and to relay derived information to worldwide users. In the Synoptic Analysis Section of this branch, special emphasis is placed on providing support to the analysis and forecasting mission of the NMC and on maintaining a surveillance program for tracking and analysis of tropical cyclones worldwide.

Over the years the Synoptic Analysis Section has participated in the development, testing, and application of a variety of tools and procedures for extracting meteorological information from satellite image data. The NESS Office of Research is engaged in a continuing project for Satellite Inputs to Numerical Analysis and Prediction (SINAP); some of the results of this project have been incorporated into daily operating procedures. In other areas the section has participated in the generation of manually classified samples of image data for use in the development of automated classifier schemes.

The Synoptic Analysis Section is the single professional group within NESS that maintains a 24-hour-per-day, seven-day-per-week worldwide weather watch. This section is collocated with the NMC Forecast Division to insure easy access to satellite information. The total complement of the NESS Synoptic Analysis Section is 16 meteorologists. One supervisor and two general meteorologists are assigned to each eight-hour shift. Several routine activities of the Analysis Section, particularly those connected with the use of geostationary satellite data, are described herein.

SUPPORT EQUIPMENT

The Synoptic Analysis Section is equipped for several functions; the equipment and how each item is used are listed in the paragraphs below.

One Alden facsimile recorder--used to obtain meteorological information from the NWS National Facsimile Circuit. This information, compared and blended with the satellite data, becomes the foundation for all products of the Synoptic Analysis Section.

Two Data Log recorders--used to obtain and provide hard copy imagery in real time from both polar orbiting and geostationary satellites.

A second Alden recorder--used to receive computer processed and stretched gridded ITOS SR imagery.

Projectors--used to view movie loops prepared from GOES data. Atmospheric vertical motion and flow pattern changes during the previous 12 and 24 hours are interpreted and evaluated by use of the film loops.

INPUT FOR NUMERICAL MODELS

The Synoptic Analysis Section supports the NMC through regularly scheduled briefings and by computer inputs to the primitive equation and limited-area fine mesh models. The GOES individual images provide needed meteorological information at synoptic times for computer input. Pictures, available at one-half hour intervals, and 12-hr movie loops provide further information about meteorological developments, changes, and movements.

The Aviation Weather Branch of NMC monitors computer-derived analyses and prognostic charts using the 300-mb surface as the control level. Differences are noted between the hand drawn analyses and the machine-derived 12-hr first-guess prognoses verifying at the time of each analysis. Where differences are deemed to be meteorologically significant, manually prepared "bogus" data are entered into the computer data base to adjust the numerical product. Within NESS, the Synoptic Analysis Section compares the GOES imagery over the North Atlantic and North Pacific Oceans with the 300-mb trough and ridge positions and cyclone centers on the first-guess numerical prognostic charts. Movie loops are also used to derive 300-mb flow lines. NMC Aviation Weather Branch personnel are then briefed on the satellite-implied differences before they prepare their hand drawn 300-mb control analysis, and necessary adjustments to the analysis are made.

MOISTURE INPUTS FOR NUMERICAL WEATHER PREDICTION

The first-guess 12-hr moisture prognosis from the Primitive Equation (PE) model is compared with the GOES imagery in the Gulf of Mexico and the Western North Atlantic Ocean and the Eastern North Pacific Ocean. Using empirically derived rules based on cloud type and pattern, the computer derived average relative humidities in the 1000- to 700-mb and the 700- to 500-mb layers are adjusted. Bogus moisture values are prepared, punched on cards, and entered into the computer for the operational analysis and forecast run. The interpretation technique is based upon a method described by Smigielski and Mace (1970). This satellite input affects machine forecasts of precipitable water and precipitation. Within the United States, this added information also augments the guidance material used by forecasters in the Basic Weather and Quantitative Precipitation Forecast Branches of NMC.

SUPPORT FOR THE NMC SURFACE ANALYSIS

In briefings for the NMC Surface Analysis Branch, GOES imagery is used to identify the existence and position of: Surface fronts, surface cyclones, trough and ridge lines, indicators of cyclone deepening or filling, frontal structure strengthening or filling, and frontal waves.

The movie loops are used to estimate cyclone intensity and to identify possible hazards for mariners such as areas of strong surface winds. In the latter cases, the NMC Marine Forecaster is alerted.

SUPPORT FOR AVIATION WEATHER

The Aviation Weather Branch of NMC prepares high and low level forecasts of significant weather for aviation interests for the North Atlantic Ocean and the United States and a high level forecast for the North Pacific Ocean. (The high levels are the 400- through the 150-mb surfaces; low levels are those below the 400-mb surface.) These forecasts indicate cloud type and amount, cloud top height, amount of jet stream-associated cirrus clouds, and areas of icing and turbulence. The aviation forecaster depends heavily on computer derived products for initial guidance.

In support of this activity the NESS analyst compares the satellite imagery with the PE, 500-mb and vorticity analyses and notes discrepancies in data sparse areas. Cloud top heights are derived from temperatures extracted by the MMIPS and areas of probable icing are indicated by analysis of a temperature slice field obtained from the ITOS infrared data. Continuity of system movement and cloud pattern is then compared with the 12- and 24-hr forecast. Current satellite pictures and model indicators empirically derived from the satellite imagery are used in preparing a 24-hr first guess cloud forecast. The resulting cloud forecast is compared with the numerical guidance. The NMC aviation forecaster is then briefed as to the differences between the satellite information and the numerical guidance. Available GOES movie loops are used to update the initial cloud forecasts and to brief the aviation forecaster as to the strengths and weaknesses of the initial forecast. Indicators of probable turbulence areas will be added to the NESS formal briefing package when techniques are developed to extract this information from satellite data.

TROPICAL STORM WARNINGS AND CLASSIFICATION

VISSR imagery is used to monitor tropical cyclone development in the North Atlantic, the Gulf of Mexico, and the eastern North Pacific. Dvorak (1973) devised a classification technique to determine the relative strength and development trends of tropical systems through the use of satellite pictures. The classification system defines "T" numbers which range from T 1.5, for an incipient storm, to T7 or T8, for a superstorm. The technique deals with development, ongoing changes, and changes in intensity in the 24 hours subsequent to the current analysis. Synoptic Analysis Section personnel coordinate the analyses and discuss indications for each disturbance with the NESS Field Services Station personnel in Miami and San Francisco. These classifications are then discussed with the NMC and the U.S. Fleet Weather Facility, Suitland, Maryland. Currently, 24-hr forecasts of position and intensity are also prepared using the system, but they are being used for test purposes only, pending further evaluation of the forecast method.

PRODUCTS FOR NEWS MEDIA DISTRIBUTION

A special movie loop is prepared and distributed to the national television networks. Synoptic Analysis Section personnel provide a written discussion describing the general weather conditions visible in the loop.

A specially prepared section of a GOES picture covering the United States and a written description of the general weather it depicts are made available to the Associated Press and United Press International wire services for distribution. Conventional surface observations and analyses are used in the preparation of the discussions.

PROJECTED ACTIVITIES

Synoptic Analysis Section activities continue to evolve both in terms of products and in the use of new tools and techniques. Several current endeavors are described below.

Snow cover analysis techniques have recently been developed by Wiesnet (1974). After a period of operational testing, routine responsibility for snow cover analysis has been assumed by the Synoptic Analysis Section. Although the method now relies primarily upon VHRR data inputs, means are being considered for using the more frequently available VISSR data.

Tracking of the shape and location of the Gulf Stream off the east coast of the United States appears to be another responsibility likely to be assumed operationally within the Synoptic Analysis Section. (See work done by Stumpf 1974). Initially, VHRR data are being used in the technique development because of the 1-km resolution of the thermal channel information. However, the suppression of noise in the VHRR analog signal results in a coarsening of spatial resolution. Since the digital VISSR data are less noisy than the VHRR data, no loss in spatial resolution occurs. Therefore, the more frequently available 8-km resolution VISSR IR data are used as an alternate source of information for this analysis effort. Mercator mapped VISSR IR data probably will evolve as a major input, and the

Gulf Stream analysis will eventually become a Synoptic Analysis Section responsibility.

In terms of analytic tools, there has long been need for more convenient ways to combine NMC's contour charts with satellite imagery. In an early (1969) effort, Shellman produced mapped images with melded contour fields. (See figure 14-1.) With increased liaison and dialogue between NMC analysts and the NESS Synoptic Analysis Section, there is renewed pressure for such a tool. While melding of contours and mapped imagery is being reexamined, impacted computer resources will likely limit such production, so a less costly alternative is also being considered. An unmapped VISSR image has been combined with NMC-produced contours using automatic gridding software, but this effort is still experimental. (See paper 5 of this memorandum.) The use of either mapped or unmapped images provides a ready means for intercomparison of cloud fields and the cloud-supporting graphic indicators produced by numerical weather analysis and prediction.

As human analysis tasks evolve into more objective procedures, they lend themselves to automation. However, more subtle tasks always seem to evolve in which the eye-brain skills are the only means for extracting useful intelligence from image data. Until the ultimate, automated ideal processor is developed, we see continuing need for professional interpreters of satellite image data.

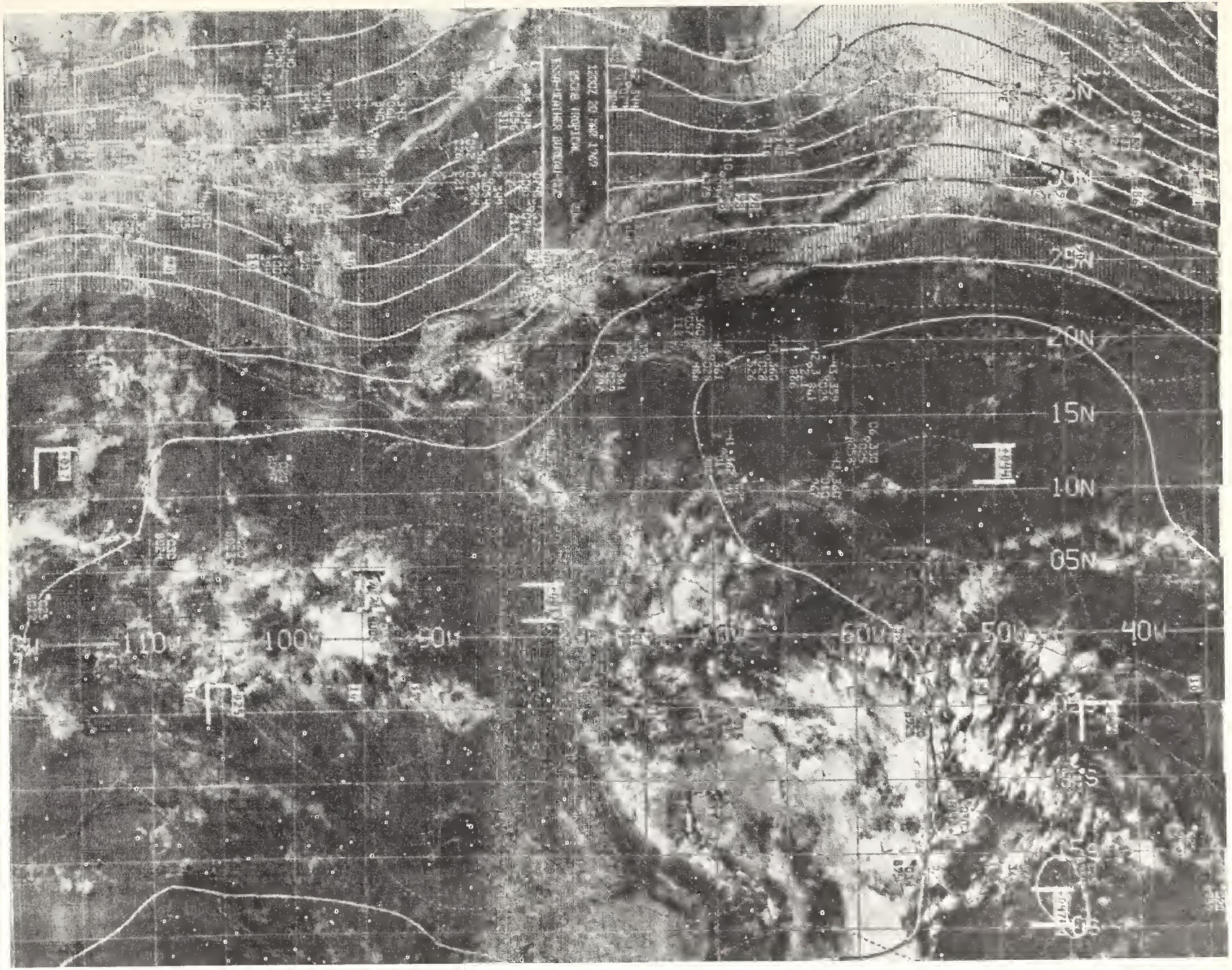

Figure 14-1.--Early mapped ATS image with melded weather chart contours show the feasibility of such combinations.

15

SEA SURFACE TEMPERATURE FROM VISSR DATA

J. A. Leese and J. D. Tarpley

INTRODUCTION

In section 13 of this memorandum, M. Young has described a man/machine procedure for extraction of cloud top temperatures from VISSR data, and, in a separate memorandum, Conlan (1973) has documented operational procedures for extracting sea surface temperature observations from ITOS IR data. Our purpose is to describe current efforts toward the automatic extraction of sea surface temperatures from VISSR data and, incidentally, to discuss a related procedure for extracting cloud-top temperatures for certain cloud regimes.

Because of the problems in VISSR data calibration (see section 8 of this memorandum), the generation of sea surface temperature gradients is treated as an alternate product development effort.

SEA SURFACE AND CLOUD-TOP TEMPERATURES

Ideally, if Sea Surface Temperature (SST) is derived from VISSR IR data alone, then both day and night measurements are available. As in the single channel ITOS approach (Leese, Pichel, et al., 1971), this requires that IR data provide the sole means for reducing the effects of noise in the signal and elimination of cloud contamination. Because the digital VISSR IR data contain less noise than ITOS SRIR data, the ability to distinguish automatically between clouds and sea surface is improved with VISSR data. Current separation efforts exploit the attributes of thermal brightness topographies.

In a field of infrared data, surfaces of uniform temperature are characterized by small first and second horizontal derivatives of temperature. The sea surface and relatively smooth cloud tops have a nearly uniform temperature and small horizontal temperature gradients, while areas with variable cloudiness or varying cloud height have large temperature gradients. The magnitude of the temperature gradient can be used to separate the cloud tops and sea surface.

Sea surface temperature and cloud top temperature are extracted as discrete values from specified target areas. The targets are formed by dividing the infrared data into contiguous arrays, each of which is processed for SST or cloud top temperature or both. The target arrays used so far have contained 16 scan lines by 32 overlapped samples along a scan line. The targets are about 110 km on a side.

Each target is processed in the following way:

1. The first and second derivatives of temperature along a scan line are computed for each point in the array. True horizontal gradients are not used because the component of the gradient across the scan line contains errors caused by misregistration of the scan lines.

2. If the first and second derivative at each point in the array are greater than a threshold value, the data point is discarded from the set.

3. Retained samples are distributed in a temperature histogram which contains a mode associated with each smooth temperature surface within the target array.

Figure 15-1 shows an example of histograms before and after high gradient samples have been deleted. In the reduced population histogram, the warm mode yields sea surface temperature and the colder mode represents a uniform cloud top temperature.

Any target array which contains several relatively smooth temperature surfaces can produce a multimodal histogram. For example, a completely overcast sector containing low and high cloud layers will produce a histogram similar in shape to a sector with a partial high cloud layer and cloud free segments. Distinguishing between such cases is difficult if one restricts input information to IR data alone. Several methods for discriminating between the two kinds of situation are under investigation. These include check of neighboring areas, comparison with sea surface temperature fields, and cloud indentification by histogram classification and discrimination. Yet to be explored are possible twice-daily linkages to ITOS-derived sea surface temperatures, or procedures which use coincident VISSR data from two or more SMS/GOES spacecraft within the broad overlap zone.

Measurements obtained with the above approach are relative brightness temperatures that are not corrected for atmospheric attenuation. With current VISSR calibration problems, results may deviate from true values by several degrees K. However, in a relative sense, one may use the warmest mode as the surface reference and then, profitably, isolate cloud layers into approximate altitude levels.

SEA SURFACE TEMPERATURE GRADIENTS FROM VISSR DATA

Since difficulties with the absolute calibration of the IR channels combined with the difficulty of correcting for atmospheric attenuation by water vapor preclude the derivation of accurate SST values from SMS-1 IR data, it is more fruitful to extract temperature gradients. A straightforward calculation of SST gradients is also precluded by the presence of moisture gradients in the atmosphere. Visible evidence of such gradients can be found by an examination of loop movies from geostationary images and watching the formation and decay of large cumuliform cloud masses. Differences between the two fluids can be used to advantage to determine SST gradients except in the special case when the atmosphere is calm.

Let us start with the equation for determining the SST value from IR data:

$$T_b + \Delta T_A = T_S \tag{1}$$

where T_b is the equivalent black-body temperature measured from the IR sensor; ΔT_A is the equivalent temperature due to water vapor attenuation in the atmosphere; and T_S is the sea surface temperature. Taking the gradient of each term in eq (1) gives:

$$\nabla T_b + \nabla(\Delta T_A) = \nabla T_S \tag{2}$$

If we could assume that the water vapor is uniformly distributed in the atmosphere, then the second term in eq (2) is zero and the gradient of the IR temperature is the same as the SST gradient. Since this is not the case, we need to examine the temporal changes in eq (2). The total derivative of this equation is:

$$\frac{D(\nabla Tb)}{Dt} + \frac{D[\nabla(\Delta T_A)]}{Dt} = \frac{D(\nabla T_S)}{Dt} \tag{3}$$

Expanding the total derivative we get:

$$\frac{\partial(\nabla T_b)}{\partial t} + \vec{C} \cdot \nabla T_b + \frac{\partial[\nabla(\Delta T_A)]}{\partial t} + \vec{V} \cdot \nabla(\Delta T_A) = \frac{\partial(\nabla Ts)}{\partial t} + \vec{C} \cdot \nabla T_S \tag{4}$$

where

$\vec{C}$ is the current or vector motion of the ocean surface; and

$\vec{V}$ is the vector motion of the atmosphere.

Under normal conditions the advective terms involving water and atmospheric motion differ by at least two orders of magnitude. If we consider an IR sensor field of view (resolution) of an order of magnitude of 10 km and atmospheric motion at 10 m/s, then, in the 30-min interval between pictures, the atmosphere over a geographical area the size of the sensor field of view has changed almost twice; whereas the ocean surface over this area has hardly changed at all. Since the effects of water vapor attenuation take place mainly in the lower two kilometers of the atmosphere, we are dealing with gradients of ΔT_A on the same scale as cumuliform cloud groups. Therefore, a sampling at half-hour intervals over a period of hours will significantly reduce the effects of water-vapor gradients in the atmosphere and yet will have very little effect on the SST gradient. Mathematically, this can be expressed as:

$$\overline{\nabla T_b} + \overline{\nabla(\Delta T_A)} = \overline{\nabla T_S} \tag{5}$$

where the bar refers to time averages.

The second term on the left side of eq (5) is reduced to a negligible value under normal conditions so that

$$\overline{\nabla T_b} \simeq \overline{\nabla T_S} \tag{6}$$

Eq (4) becomes a special case when there are calm atmospheric conditions over a large geographical area. Because moisture gradients can be essentially constant over the period of calm conditions, eq (6) is invalid. Measurements of low level cloud motion vectors during the past five years have shown that this is a rare event.

Work is proceeding to incorporate the measurement of SST gradients over the three-hour time interval of manually measuring cloud motion vectors. If the work of measuring SST gradients proves successful, gradients will be incorporated with the SST observations derived from the polar satellite IR data. This will provide a more detailed analysis of the SST field in the geographical area common to the two satellites.

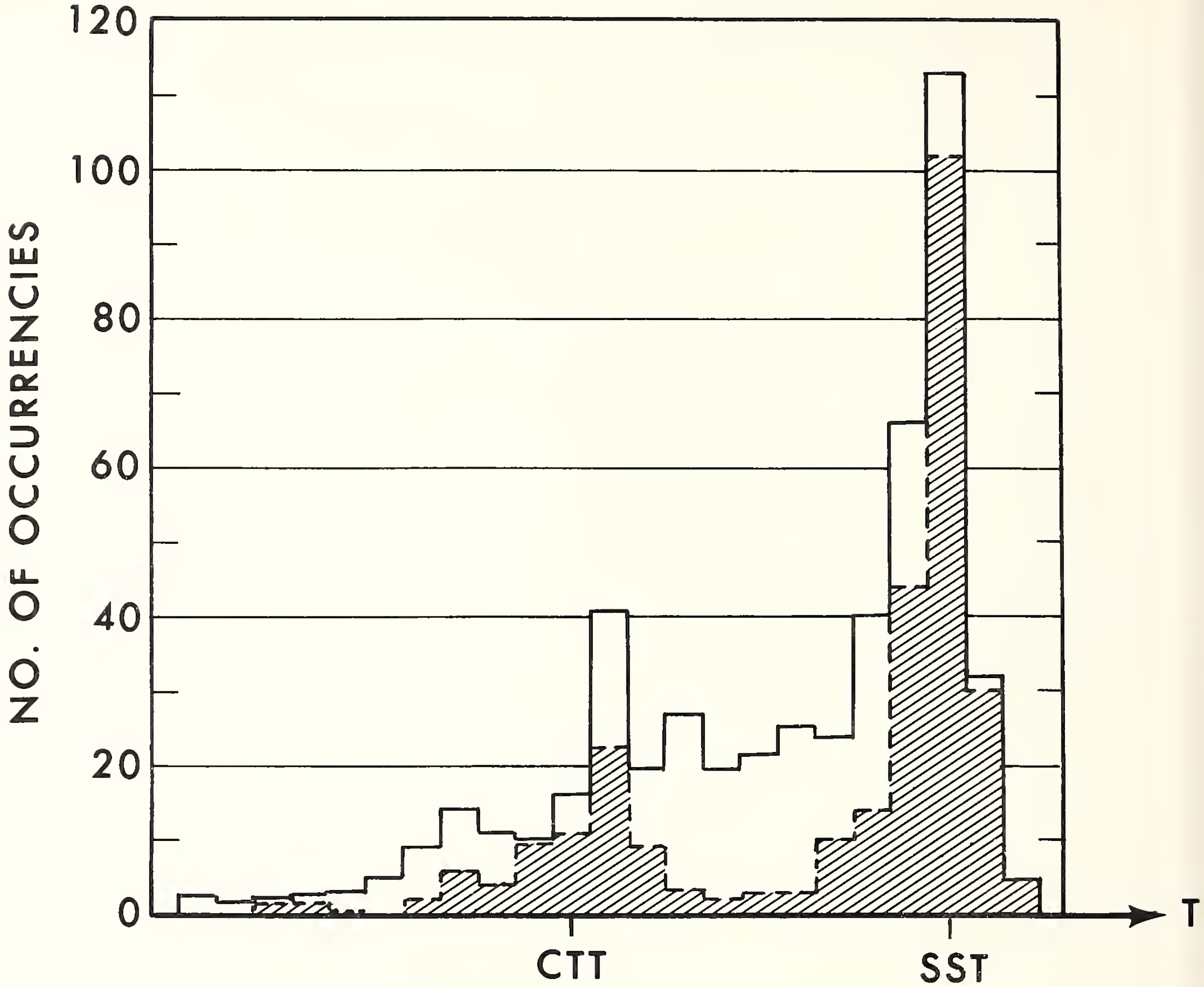

Figure 15-1.--Distribution of 16 line x 32 sample SRIR target sector observations. Upper distribution includes all observations. Lower (hatched) profile indicates the distribution after elimination of high gradient cases.

16

GOES PRODUCT ARCHIVING ACTIVITIES

L. Rubin and L. Watson

INTRODUCTION

Over the years NOAA's routine acquisition of ATS pictures has resulted in the accumulation of a substantial film archive. By agreement with NASA (ARA, Inc. 1967), the NOAA archive contains some 14,000 picture negatives from ATS-1 and 52,000 from ATS-3. Now, with day and night imaging under the dual GOES operation, we are developing a new archival posture. Since the image data arrive in digital bit streams, there is interest in preserving significant amounts in digital form. Recent advances in digital mass storage technology suggest a future substantial reduction and perhaps eventual elimination of image film archives.

Quantitative information extracted from VISSR imagery involves a marked reduction in bit volume and so is well suited to digital archiving. Routine production of such derived information is now restricted to cloud motion wind estimates.

Our main purpose here is to record what is in the archive--both in digital and in film image form--and to describe current and continuing archival effort.

THE NEW SATELLITE DATA BRANCH

In the past, requests for satellite data archived at the EDS's NCC required frequent consultation and information exchange with NESS. Recognizing the need for close liaison in filling requests, EDS and NESS recently established a new NCC Satellite Data Services Branch (SDSB), managed by EDS but collecated with NESS. Requests for archived satellite data should now be directed to National Climatic Center Satellite Data Services Branch, World Weather Building, Room 606, Washington, D.C. 20233. Questions of suitability of the requested data for the desired application or other need for coordination are now handled as an internal matter between SDSB and the appropriate expert within NESS. This procedure applies to requests for film or photo prints as well as to requests for digital information.

VISSR FILM ARCHIVES

Because of varying operational requirements, there is considerable fluctuation in VISSR data acquisition. Reaction to severe weather threats or other operational support commitments sometimes may result in shifts in geographical coverage, spatial resolution, and picture scheduling. Questions therefore arise as to what information should be retained in archival form and for how long. Ideally, all incoming data would be preserved in its original digital form, but this is not yet economically feasible. Table 16-1 reflects our current film storage archival activity. The size of all products, whether film or paper prints, is 25 x 25 cm.

Except for basic picture negatives, the animation stand and Kinescope recorder operation generates substantial quantities of time-lapse 16-mm movie films. (See discussion by Plew et al. elsewhere in this memorandum.) In one such operation, 15-m negative strips are made twice daily from each of the two operational satellites--a total of 1,460 strips per year. These strips, produced for TV weathercast use, are spliced into 30-m pairs and stored on reels. After one to two weeks, the reels are turned over to SDSB and are reviewed for further retention after one year.

Other 16-mm film loops are made for wind extraction by the NESS Winds Section in WWB and at SFSS units. With about thirty 60-cm strips per day, some 10,000 strips (fifty 120-m reels) are produced annually. NESS retains these loops for one month; longer term retention by SDSB is yet to be determined.

THE DIGITAL GOES ARCHIVE

Although large numbers of digital VISSR image tapes have been preserved in support of the GATE project, the preservation of raw digital image tapes by NESS remains an open question. A pool of reusable tapes is currently used for the picture-pair automated cloud-vector extraction operation but only limited numbers of image tapes are retained on a temporary, recycling basis.

An agenda item for the WMO Panel on Meteorological Satellites is in regard to the establishment of a specific format for very high density magnetic recording of digital VISSR data. Once a format is established, a recording facility probably will be procured for archiving large volumes of digital VISSR data. Meanwhile, cloud motion vectors are the primary VISSR-derived digital archive.

About 570 wind vectors are archived daily from each operational satellite. Two-thirds of these vectors are derived from movie-loops; the remainder are derived by computer from digital picture pairs. Both methods rely on the use of large scale, high speed ocmputers. The movie-loop wind vectors are man selected, and computer quantified and earth located. All vectors are man edited prior to archiving. (See paper 13 for a more detailed discussion.) The archived daily vectors are batched and written onto an archival tape once per month. Details of the tape format and content are:

Winds Vector Archival Tape Format

One archival tape contains a one-month accumulation of both movie-loop and computer-derived wind vectors.

Computer	IBM 360/195
Files	1
Records	as many as required
Record length	6,000 8-bit bytes
Element length (see below)	2 bytes or 16 bits/element (binary). Where applicable, negative values are in 2's complement
Vector length	15 elements
Vectors/record	N vectors (N=1 to 200); if N is less than 200, record will be zero filled
Trailor record	200 zero element vectors
Recording mode	binary
Density	1600 BPI
Tracks	9 track

Vector description by element:

Element No.	Description
1	Year, e.g., 4 = 1974
2	Month, e.g., 11 = November
3	Day of month
4	Hour, e.g., 14 = 1400 GMT
5	Pressure in tens of mb, e.g., 55 = 550 mb.
6	Temperature in °K (whole degrees)
7	Latitude x 10, e.g., -788 = 78.8°S
8	Longitude, °W x 10, e.g., 1903 = 169.7°E
9	Direction in degrees
10	Speed in knots
11	Octant, standard global octant (N-0, 1, 2, 3), (S-5, 6, 7, 8)
12	Count*, 1-9999, unique for each vector on a given run
13	Source code, 1 = Suitland, Md.
14	Height confidence factor, 0-9, low to high
15	Total confidence factor, 0-9, low to high

* Computer derived wind vectors will start with 501.

Tape copies in the above format are available through SDSB at nominal cost.

Current investigations toward the extraction of other quantitative products will likely generate additional digital VISSR archives. Sea surface temperature extractions are likely, but specific operational plans were not yet firm in late 1974. As new items are added to the archive, details will be published by SDSB.

THE SPACE ENVIRONMENT DATA ARCHIVE

The Space Environment Monitor Subsystem (SEMS), built by Philco-Ford to specifications of NOAA's Space Environment Laboratory (SEL), provides data on conditions in space, with special emphasis on environmental factors dependent on solar activity. The sensor package contains three monitors to measure energetic particles, magnetic fields, and solar x-rays. The SEMS is designed to provide data for use in real time and for subsequent analysis by SEL. After initial checkout, the data from SEMS will be sent, after a period of one year, to the National Geophysical and Solar-Terrestrial Data Center (NGSDC) for archiving and subsequent management. SEL will maintain a SEMS data library for its own needs.

Energetic Particle Sensor (EPS)

The EPS has five solid state detectors to measure incident protons in eight ranges from 0.8 MeV to 500 MeV, alpha particles in 6 ranges from 4.0 MeV to 302 MeV, and electrons at energies greather than 2.0 MeV. The measurements will be recorded on magnetic tape for subsequent processing by SEL and NGSDC. Format and quantity of data to be recorded or archived on magnetic tape and on microfilm is yet to be determined.

Magnetometer

The magnetometer, consisting of two fluxgate sensors, utilizes the satellite spin to measure the magnitude and direction of the ambient magnetic field. A combination of stepped offset and range selection permits a sensitivity of 0.1 gamma with a range of ± 1200 gamma. On-board low-pass filters are used to eliminate aliasing and to limit the bandpass of the recorded signal to less than 0.135Hz. Format and quantity of data to be recorded or archived on magnetic tape and on microfilm is yet to be determined.

Solar X-ray Sensor

The solar x-ray sensor consists of two ion chambers which respond to x-rays in two bands: 0.5 to 3 Å, and 1 to 8 Å. The sensor will point directly at the sun once every spin of the satellite, thus permitting continual monitoring of solar x-ray output. The data will be recorded on magnetic tape for subsequent processing by SEL. Format and quantity of data to be recorded or archived on magnetic tape and on microfilm is yet to be determined.

SEMS data are handled directly by SEL; NESS responsibility is confined to assistance in raw data acquisition. In terms of the NESS earth environment sensing mission, these data are considered outside the primary scope of this report. Further inquiry on details of the space environment program should be directed to the National Geophysical and Solar-terrestrial Data Center (NGSDC), Boulder, Colo.

Table 16-1.--VISSR image archive

Sensor channel	Spatial resolution (Km)	Format	Quantity per day per satellite	Total pieces per yr	Retention time at SDC	Film (F) or paper print (P)	Remarks
IR	8	Full disk	40	29,200	5 yrs.	F	EDS/NESS review before disposal
VIS	4	Full disk	32	11,700	5 yrs.	F	EDS/NESS review before disposal
VIS	2	Quarter disk	32	11,700	open	F	Indefinite review after 1 yr. retention at NESS
VIS	1 and 2	Variable size and location	280	102,000	open	F	Retained 1 month by SFSS, further retention to be determined
VIS	1 and 2	Designated sectors	364	133,000	none now planned	P	Retained at SFSS or WSFO three months, then deposited with cooperating universities for library use.

17

QUALITY ASSURANCE AND PRODUCT MONITORING

D. MacCallum

INTRODUCTION

Quality Assurance is certainly not a new concept for management, but it is a thoroughly viable concept that has been tested over the years in both government and private industry. It is used as a management vehicle to insure that a given operational system provides products and services that meet organizational mission requirements. In terms of operational sensor systems, this implies (within the limits of the hardware, software, and personnel support capabilities) that necessary, accurate, and timely observational data will be delivered to the user or to user transmission points in usable format and with minimum delay.

A logical breakdown of elements for the quality assurance program is: Spacecraft System, Sensor System, Data Collection, Data Processing and Production, and Data-Product Dissemination. In each area, the following functional tasks are necessary:

Measurement: collection of samples, parameters, statistics, etc.

Evaluation: graphing, charting, intercomparison of measurements, and comparison of measurements against standards.

Problem identification: interpretation of the measurements and evaluations of possible substandard performance and its causes.

Feedback: design of techniques based on problem identification output to prevent, correct, or filter problems or failures, and to redefine standards as needed.

NESS formally introduced a limited quality assurance program in late 1972, following the launch of NOAA-2. Initially, this program was used for monitoring only the data collection, data processing, and data-and-product dissemination of the SR. Later, monitoring of VTPR, SR, and VHRR data, all from the polar orbiting satellites, and of the ATS-3 spin scan data were added to the program. Parts of the spacecraft and sensor system monitoring responsibilities were added to the program.

The quality assurance unit, now, officially, the Operational Product Monitoring Section (OPMS), must interface with nearly all of the other units within the NESS Office of Operations. To accomplish its functions, the OPMS has eight people, six professionals and two technicians. Four of the professionals perform round-the-clock monitoring seven days a week, one professional is the senior analyst, one professional is the supervisor. The two physical science technicians accumulate and format the bulk of the statistics. The professionals are meteorologists or physical scientists with related backgrounds and are familiar with computer operations, sensor capabilities, and data requirements.

Statistics are maintained on sensor calibration, product quality, product timeliness, equipment problems, as well as on probable cause factors related to problem areas. Data are acquired from shift logs, computer printouts, and other diagnostic evidence, and are plotted by technicians for analysis by professional scientific personnel. On-line monitoring and analysis of computer production is made easier by the use of a central computer facility CRT that displays job and data information within the OPMS.

SMS-1 MONITORING

Calibration Monitoring

Based on experience in monitoring the digitized output of the ATS-3 spin scan data and the early processing of VISSR data, a number of diagnostic software routines have evolved. These diagnostic routines quantitatively measure the several parameters needed to assure that the quality of data is maintained within certain specified limits. These limits are continuously refined and, as experience is gained, only those parameters exceeding certain limits will be printed for examination.

The routines used either operate on the video data or are used to examine parameters in the documentation with each line. Such items as brightness values from the histogram of the digitized data counts, step wedge values, slope of curve to check for linearity, and temperatures of key sensor points are plotted for comparison with the previous related responses. In this way, significant trends toward signal deterioration or unplanned departures can be brought to the notice of the proper personnel for evaluation or correction.

Automatic Gridding and Picture Centering Monitoring

The mechanics of automatic gridding and picture centering are described elsewhere in this memorandum. Here the operational procedures to monitor these areas are explained.

Gridding fit in VISSR imagery is a graphic method to assess the accuracy of spacecraft attitude and orbital prediction. Problems in attitude prediction are judged in terms of vertical shift in the gridding; the accuracy of orbital prediction is judged in terms of precision in horizontal centering.

Since the SMS-1 spacecraft attitude has tended to drift 0.008° per day, this drift is noticeable in gridding. It has become a function of the SOCC navigator to analyze the latest attitude information and make daily attitude predictions three to four days in the future. The observed change of attitude is entered into the program each day. The OPMS observes the vertical fit daily and relays this information to SOCC.

Horizontal picture centering requires a less active role on the part of OPMS. A PICATT-related computer program, run daily, analyzes horizon points from selected pictures throughout the day and produces a picture-centering diagnostics report. By using statistical limits, this report produces a daily modification to the Grid Tape software which attempts to correct for past errors. The effectiveness of this procedure is graphically seen in the horizontal shift in grid fit because the gridding software assumes a horizontally centered image.

Central Computer-Produced Product Monitoring

Products produced by the central computer facility are monitored by OPMS for proper processing and, to a limited degree, for meteorological consistency. Each product has a small quality control printout package that produces key diagnostic items to ease the job of failure identification or to provide evidence of successful completion of the job. The transmission of products is monitored routinely and failures, together with the probable cause of failure, are noted. Analysis of these problems contributes toward suggestions for improvement. OPMS also assists in developing and evaluating new techniques for monitoring central computer-produced products.

SUMMARY

In summary, the mission of the OPMS is to monitor in real or near real time the processing of the data, to flag problem areas so that corrective action may be initiated, to provide consultative services on interpreting diagnostic output and processing schedule deviations, to provide a central location in NESS for establishing the current status of data processing, and, through post-factor analysis, to recommend changes to improve the operation.

Although OPMS provides the major monitoring service for the central computer-produced products, items such as the SMS-1 movie loop and picture-pair wind vectors are monitored by the WIND Section and the polar orbiting VTPR is monitored by the Analysis Section. Both of these Sections are part of the Analysis and Evaluation Branch. SMS-1 products other than those described above are monitored by the Field Services Division primarily for meteorological consistency and photographic product densities.

The OPMS conducts a semi-formal briefing twice a week for all operations personnel concerned including those of the Command and Data Acquisition Stations. These briefings include a review of the previous three or four days' operations, and discussions of significant problems identified, information exchanged between units, and suspense items established and recalled. The OPMS also has an area where self-briefing material is available daily. Graphic and photo image displays are posted, and a professional member of the staff is available to answer questions. Figures 17-1, -2, and -3 are views of the monitoring area. The impact of this quality assurance effort has been an overall improvement in NESS operations resulting in an increase from an average 75% image product throughput to a more than 90% throughput during the past year. This represents a 20% improvement, which is impressive considering that during the past year there has been nearly a 200% increase in the number of products, a new central computer facility and peripherals have been introduced, a new satellite system (SMS-1) and its ground handling system have been put into operation, and NESS support to key National Weather Service Facilities has been expanded rapidly by the on-site establishment of Statellite Field Service Stations.

Figure 17-1.--Product monitor display area showing photo products and mapped images retransmitted via ATS and GOES WEFAX

Figure 17-2.--Throughput monitoring station showing job-status keyboard

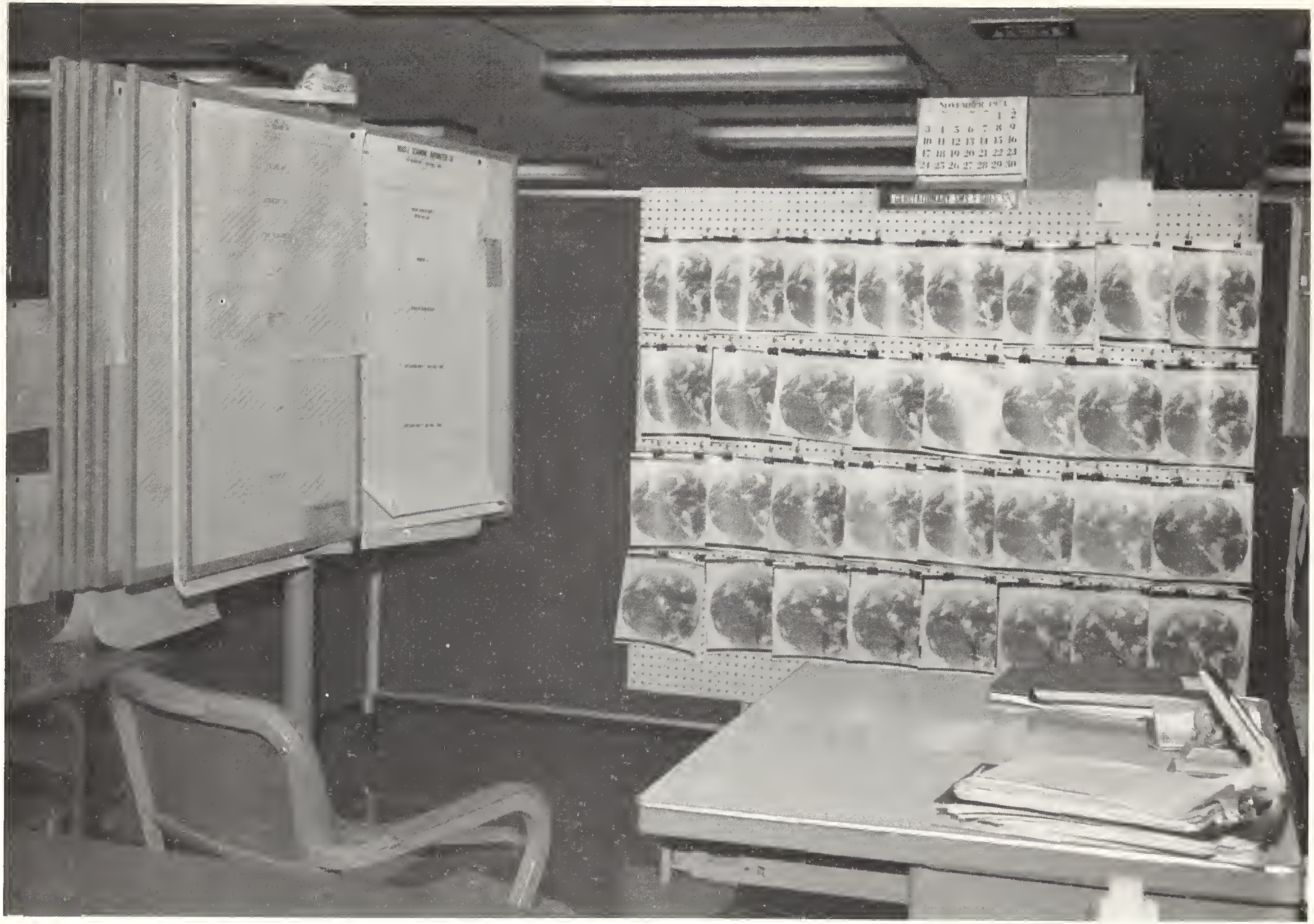

Figure 17-3.--Monitoring area showing specimen VISSR images and graphic plots

18

FURTHER OUTLOOK FOR GOES

D. B. Miller, J. A. Leese, and C. L. Bristor

INTRODUCTION

Projective discussions included in several of the preceeding segments of this memorandum have been mainly short term in nature. Although a few shorter term items are added below, the present purpose is to discuss some longer term prospects and possibilities. While in some areas problems now seem to predominate over solutions, new ideas and recent hardware developments justify continuing review. Projections are grouped under two general categories: developments in the software/hardware data handling capabilities, and applications developments which lead to new or improved products. The first category requires continued monitoring of new product offerings and advancements in technology. In the latter case there seems to be little lack of new ideas. The need is rather for conservatism to assure the adequacy of resources and a proper economic payoff.

NEW MISSIONS AND PRODUCTS

Inter-Intra Satellite Calibration:

Earlier sections of this memorandum discuss calibration and the prospects for sea surface temperature measurements from VISSR data. A major problem in GOES data processing is the calibration of the VISSR sensors and the intercomparison between these sensors and the Scanning Radiometer (SR) on the NOAA polar orbiting satellite. As a longer range solution to this problem we are working toward the use of the overlap region between the two GOES satellites stationed at 75°W and 135°W longitude. The two satellites at these locations provide good overlap coverage about 30 degrees longitude wide at the Equator. This overlap can be used to compare the two VISSR sensors at any time of the day. Twice per day the SRIR data will also be available from this same overlap region. It is planned to make use of this overlap region to assure compatible calibration among the two VISSR IR sensors and the SRIR sensor. Once sea surface temperatures are extractable from VISSR data in the absolute sense, then it appears that our customer base will expand because of the continuous availability of source data.

Atmospheric Soundings:

For several years NASA and NOAA resources have been committed to the development of a VISSR Atmospheric Sounder (VAS). With initial impetus from Professor V. E. Suomi, the effort has passed through several phases. The configuration, now in the detailed electronic design phase, is described in a recent design review report by the Santa Barbara Research Center (1974). In brief, the instrument will replace the present VISSR in terms of spacecraft interfaces, but an expanded sensor channel configuration will not only provide indirect sounding capability but also will provide additional imaging channels. As presently projected, this instrument will likely become operational with the launch of the fifth or sixth spacecraft in the SMS/GOES series.

Once operational, VAS will substantially alter the NESS operational mission. Sea surface temperature extraction will provide an improved means for making corrections to atmospheric soundings, and the resultant increase in frequency of soundings will enhance our ability to provide atmospheric measurements for inputs to numerical weather prediction.

Pattern Recognition Techniques:

Developments in pattern recognition are periodically reviewed for possible mission impact. Kanal (1974) has recently reviewed the state of affairs in pattern recognition. A few application prospects are under consideration.

One possibility involves the analysis and classification of histograms. Very promising results have come from a set of statistical tests using Pearson's frequency curve classification scheme with root beta-one and beta-two parameters (Pearson and Hartley, 1972). This statistical procedure promises to classify very finely the type of distribution that is extracted from any given segment of VIS or IR data. To date, some 50 distinctive distribution curve types have been classified uniquely from VISSR sample areas. The procedure not only can name the type of distribution observed, but can produce the best fit equation for the distribution. Once the physical relationships represented by the various histogram types are known, this classification system will be a powerful tool for automatically determining characteristics of scene samples. Cloud type and cloud amount are but two characteristics which may be uniquely determined by this technique.

SEVERE STORM POTENTIAL ANALYSES

Pattern recognition techniques may also be applied to the analysis of the IR radiation field patterns that may be distinctive precursors of severe convective outbreaks. It has been shown that severe weather outbreaks occur in the clearest regions of the central U.S. (Purdom and Gurka 1974). Also the motion of arc clouds, which mark the downrush from existing convective storms, can often "trigger" new severe weather outbreaks (Purdom 1974). Pattern recognition techniques that enhance and identify the surface thermal gradients need to be developed to quantify these two observed phenomena. Half-hourly thermal gradient maps would delineate the relative hot and cold "tongues" that seem to be necessary conditions for certain kinds of severe weather generation.

Once the severe weather convective systems have begun, enhancement techniques applied to the cloud tops may offer clues as to the most hazardous parts of the storms. "Overshooting tops" may be delineated by simple gradient or curvature enhancement techniques. These edge enhancement techniques would aid the field forecaster in following the development and movement of the most severe portions of the storm system.

Data Blending:

In another area, there are analysis techniques for blending gradients of scalar fields with point values. This approach can obviate the need for absolute calibration of IR data. Ground temperature values blended with IR gradient values could present a more detailed thermal analysis than is possible from either data set independently. This technique can be applied to both land and sea surface temperature analyses.

Land Mark Registration:

Apart from product-oriented mission developments, we have a continuing support responsibility for spacecraft operations. With projected reduction in NASA support for spacecraft navigation, we are exploring ways for NESS to improve its posture in this area. As mentioned earlier, attitude determination from landmarks was part of the routine operations for ATS image processing, and inputs for attitude determination were obtained from the landmark registration used in the Picture Pair method of computing cloud motion vectors. There has been a great interest in extending the use of landmark information to obtain orbital elements as well as attitude. Previous efforts using ATS image data have not been very successful. Recent experiments using SMS VISSR data have shown more positive results, and there is reason for a high degree of optimism that it will be possible to obtain both orbital elements and attitude from SMS image data. Our current work in this area is being done jointly with a group at the NASA Goddard Space Flight Center, headed by Dr. C. E. Velez, Chief, Systems Development and Analysis Branch. The goal is to demonstrate the feasibility of getting both orbital elements and attitude from image data.

Image data were obtained during a 60-hr period covering Aug. 24-26, 1974. Processing of these data to obtain about 10 landmark locations in the image domain from each of 29 different pictures is now going on. In addition, the locations of the ellipse centers of 31 different pictures are being derived. Preliminary results using information from only six pictures shows good agreement in the orbital elements with that obtained from the Goddard range and range-rate system.

Results to date indicate that one of the most important factors in determining the operational feasibility of using landmark data to obtain both orbital elements and attitude is the degree to which the landmark information needs to be dispersed over a 24-hr period. Problems were particularly acute in determining landmark locations from IR data at night. Four IR images, taken at night, were analyzed; it was possible to obtain the location of only four to six landmarks from each image using manual techniques alone. The lack of large land-water temperature gradients at night, coupled with the time lag in the sensor response to temperature changes, are two important reasons why it is difficult to obtain landmark locations from nighttime IR data.

Calculations indicate that the use of computer signal processing techniques can detect temperature gradients an order of magnitude smaller than those detectable by manual analysis of the raw imagery. This factor, combined with the preliminary results obtained, enables us to be very optimistic that we can eventually develop an operational procedure for obtaining orbital elements and attitude from landmark data obtained from the VISSR images.

THE IMPACT OF NEW FACILITIES

Digital handling of high volumes of satellite data is by far the major problem to be solved if we are to make significant progress in the area of computer derived image and quantitative products for operational applications. Although present efforts to pass data more automatically to the large scale computer should improve our operation, the shear volume of raw data restricts processing to only a small percentage of available data.

Preprocessing of each GOES image takes approximately 15 minutes clock time on the IBM 360/195. Preprocessing software improvements can reduce the time needed by about 50%, and main memory requirements will likely decrease by about 40%, but resource requirements are still too large to consider preprocessing a large number of GOES images on the IBM 360/195. As a longer range solution to the problem, we are transferring the preprocessing job from the large computer system to the VISSR ingest computer. This will be done by attaching disk packs to the minicomputer that handles the ingest of the VISSR data. The net result of this change is to free more time for image processing on the IBM 370/195. On a still longer range, we are examining the use of a large random access mass memory for storing digital image data. It is hoped that such storage will have a capacity to store all the image data from two GOES satellites for at least five days. Such storage capacity will enable us to respond to the requirements for multi-day composite image data for applications such as snow cover mapping. Two other major benefits of such a large storage device are that it will enable us (1) to even out the processing load on the IBM 360/195, and (2) to archive VISSR data in digital form.

The exciting trends in microprocessor technology are suggesting likely downstream alternatives for digital image processing. According to current literature, substantial advances in speed and feature sophistication are coming hand-in-hand with decreasing costs (e.g., see Shmid, 1974). Apart from laboratory applications, as emphasized by Pike (1974), it seems likely that this new technology will also provide alternatives to large scale computers for operational image data processing.

Current work in "pipeline" designs suggests the tradeoff between large scale "serial" computation and the investment in processing modules which handle individual steps in the calculations (e.g., see Lillestrand 1972, and Wishner 1972). Whereas earlier approaches mainly involved "hardwired" special purpose modules, it now appears that more versatile microprocessors will better meet the challenge while also permitting flexible reconfiguration for changing missions.

CONCLUDING REMARKS

Substantial progress has been made over the past eight years in the extraction of useful environmental observation from geostationary spin scan imagery. Considering the exploratory nature of the early ATS imaging effort, credit is due those involved for achieving a stable experimental operation. Experience gained was most valuable in helping to define the SMS/GOES spacecraft and ground systems.

Some of the projective ideas expressed above will likely gain common support and become a part of future operations. Although meteorological application efforts predominated earlier, there is now increased resource commitment within NOAA for the exploitation of geostationary satellite imagery for oceanographic interests. Considering preparations now underway by other nations, the late Seventies should be a period of accelerated development in extracting environmental products from geostationary satellite image data.

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